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PRESSURE DISTRIBUTIONS ON A CYLINDRICAL SURFACE BEHIND SHALLOW THREE-DIMENSIONAL REARWARD-FACING STEPS AT MACH NUMBERS FROM 0.4 TO 1.3

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16. Abstract

An investigation has been conducted in the Langley 16-foot transonic tunnel to determine static pressure distributions along a cylindrical surface behind a shallow three-dimensional rearward-facing step of varying height. The ratio of step height to model maximum diameter ahead of the step varied from 0 to 0.27. The investigation was conducted at Mach numbers from 0.4 to 1.3 and at angles of attack from -5° to 12°. The Reynolds number per meter varied from 4.90×10^{6} to 14.10×10^{6}.

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SUMMARY

An investigation has been conducted in the Langley 16-foot transonic tunnel to determine static pressure distributions along a cylindrical surface behind a shallow three-dimensional rearward-facing step of varying height. The ratio of step height to model maximum diameter ahead of the step varied from 0 to 0.27. The investigation was conducted at Mach numbers from 0.4 to 1.3 and at angles of attack from -5° to 12°. The Reynolds number per meter varied from 4.90×10^{6} to 14.10×10^{6}.

INTRODUCTION

A previous investigation at subsonic and transonic speeds (ref. 1) was concerned with measuring base pressure of shallow rearward facing steps and the pressure distributions ahead of these steps. Reference 2 presents supersonic results of step base pressure and pressure distributions downstream of the step. The present investigation extended the range of measurements to the region downstream of such steps at subsonic and transonic speeds. Since steps of this type generally occur in the manufacture of missile and aircraft configurations, this information would be helpful in determining the use of such steps for venting of an internal compartment (ref. 1). The present investigation was conducted in the Langley 16-foot transonic tunnel at Mach numbers from 0.4 to 1.3 and an angle-of-attack range from -5° to 12°. The Reynolds number per meter varied from 4.90×10^{6} to 14.10×10^{6}. The results are presented without discussion.

SYMBOLS

C_p — pressure coefficient, $\frac{p_l - p_\infty}{q_\infty}$

$C_{p,b}$ — step base pressure coefficient, $\frac{p_b - p_\infty}{q_\infty}$

d — diameter of cylindrical portion of model behind step

d_m maximum diameter of model

M free-stream Mach number

p_b step base pressure

p_l local static pressure

p_∞ free-stream static pressure

q_∞ free-stream dynamic pressure

x longitudinal distance measured positive rearward from model step base (station 182.58 cm), see fig. 1

α nominal angle of attack, deg

ϕ meridian angle, measured from top of model in clockwise direction when viewed looking upstream, deg

APPARATUS AND PROCEDURE

Model

Details and design dimensions of the model configuration used in the present investigation are shown in figure 1. Photographs showing the model mounted in the wind-tunnel test section are presented in figure 2. The forebody of the model was a 182.58-cm-long aluminum cone-cylinder with a maximum diameter of 15.24 centimeters. The cone half-angle was 14°. Five cylindrical wooden sleeves of varying diameter could be attached directly to the sting behind the aluminum forebody. The ratio of step height to model maximum diameter ahead of the step varied from 0 to 0.27. The aluminum forebody was instrumented along the top at $\phi = 0^\circ$ with a single row of pressure orifices and each of the sleeves was instrumented with pressure orifices at $\phi = 0^\circ$ and 180°. Two orifices were located on the model step base at meridian angles of $\phi = 0^\circ$ and 180°. Base pressure at the step could be measured only for the configurations with the three smallest sleeves and only at $\phi = 180^\circ$ for $d/d_m = 0.92$.

Wind Tunnel and Instrumentation

This investigation was conducted in the Langley 16-foot transonic tunnel, which is a single-return, atmospheric wind tunnel with a slotted octagonal test section and continuous air exchange. The model-support angle-of-attack mechanism pivots the sting support in such a manner that the model remains on or near the tunnel center line.

Surface static pressures forward of the step were measured on pressure-scanning devices. Base pressures at the step and static pressure on the sleeves downstream of the step were measured with individual pressure transducers.

Tests

The model was tested at Mach numbers from 0.4 to 1.3 and at nominal angles of attack from -5° to 12°. The Reynolds number per meter varied from 4.90×10^{6} to 14.1×10^{6}. To insure turbulent flow, the model was tested with a boundary-layer transition strip which consisted of No. 100 silicon carbide grit particles sparsely distributed in a thin film of lacquer. The strip was 0.25 centimeter wide and located 2.54 centimeters from the model nose.

CORRECTIONS AND ACCURACIES

The angle of attack has been corrected for wind-tunnel flow angularity but not for model deflection under load at angle of attack. Hence model angle of attack should be considered nominal. No estimate of model deflection has been made. From calibrations of the wind tunnel, the test-section wall divergence was adjusted as a function of airstream dewpoint temperature in order to eliminate any longitudinal static pressure gradients in the test section that might occur because of condensation of atmospheric moisture.

The accuracies of the data have been estimated to be

C_p . . . . ± 0.007
$C_{p,b}$ . . . . ± 0.007
M . . . . ± 0.005

PRESENTATION OF RESULTS

The results of the investigation are presented in pressure-coefficient form in figures 3 and 4. Figure 3 shows typical pressure distributions at $\phi = 0^{\circ}$ on the cylindrical forebody. Figure 4 presents both the step base pressure coefficients and the pressure coefficients along the cylindrical surface behind the step. The pressure distributions at or near $x/d_m = 0$ for $d/d_m = 1.00$ are influenced by the joint that existed between the aluminum model and the wooden sleeve. The effect of step height on the variation of step base pressure coefficient with Mach number at $\alpha = 0^{\circ}$ for three configurations is presented in figure 5. Only the step-base-pressure-coefficient data recorded at $\alpha = 0^{\circ}$ are included.

The data at $M = 1.00$ and 1.05 are subject to wall interference effects as discussed in reference 3. The data at $M = 1.10$ and 1.15 are subject to boundary-reflected-disturbance interference effects (model bow shock reflection). At $M = 1.10$ the reflected shock impinges on the model at approximately $x/d_m = -2.0$ (fig. 3(d)), and at $M = 1.15$ the reflected shock impinges at approximately $x/d_m = 2.2$ (fig. 4(l)).

CONCLUDING OBSERVATIONS

The general pattern of the pressure distributions on a cylindrical surface downstream of a three-dimensional step was an expansion of the flow immediately behind the step followed by a recompression to above free-stream static pressure and approximate recovery to free-stream conditions. The length of the expansion region increased with step size. The recompression which was very abrupt at the lower speeds became more gradual as the Mach number was increased. Increasing the angle of attack reduced the extent of the expansion region on top of the cylindrical surface and increased it on the bottom. In addition, the positive and negative pressure peaks behind the step increased as model attitude increased.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 1, 1971.

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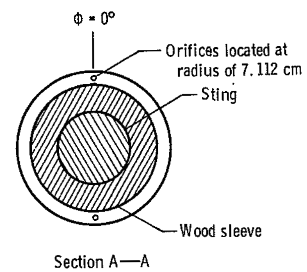
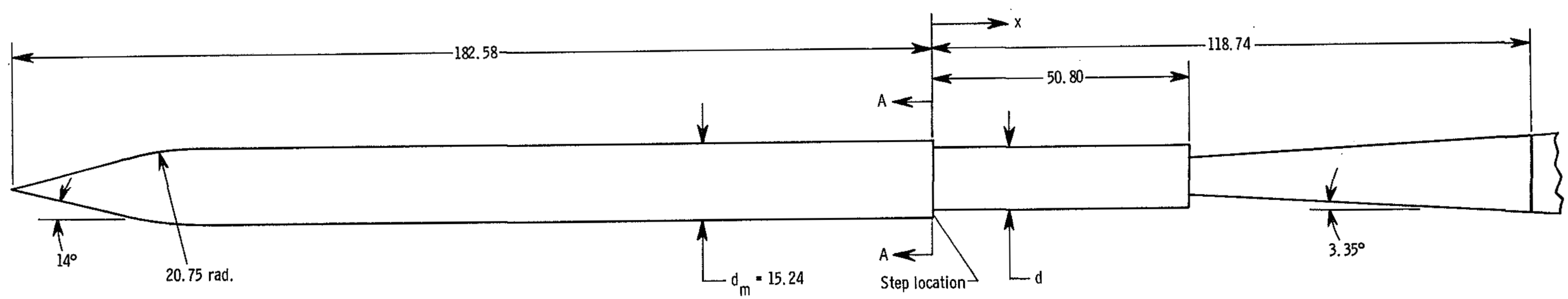
2. Beheim, Milton A.: Flow in the Base Region of Axisymmetric and Two-Dimensional Configurations. NASA TR R-77, 1961.

3. Capone, Francis J.; and Coates, Edward M., Jr.: Determination of Boundary-Reflected-Disturbance Lengths in the Langley 16-Foot Transonic Tunnel. NASA TN D-4153, 1967.

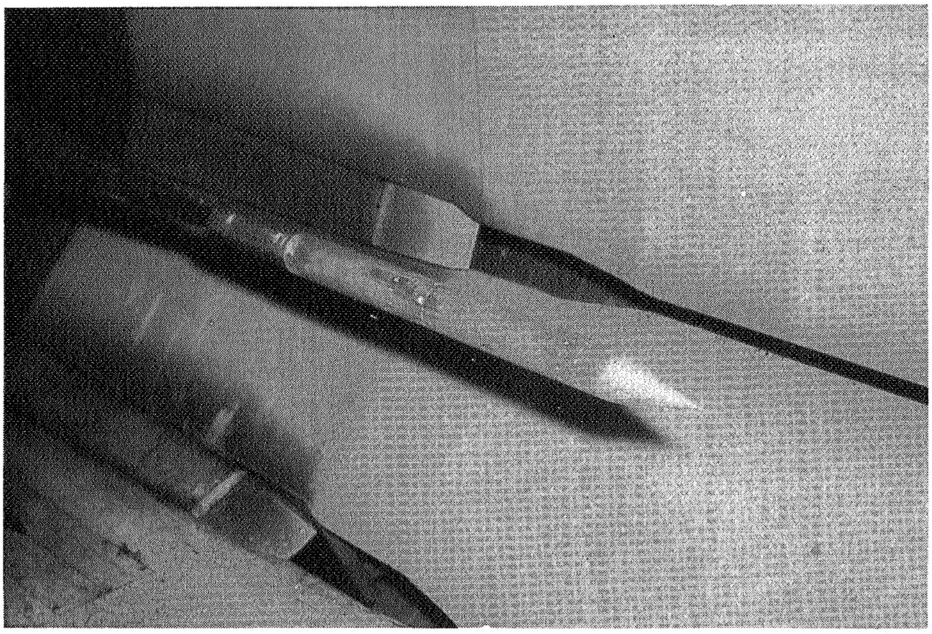


Orifice Locations			
Upstream of step		Downstream of step	
x, cm	x/d_m	x, cm	x/d_m
-68.58	-4.500	0.76	0.05
-64.77	-4.250	1.52	.10
-60.96	-4.000	3.05	.20
-57.15	-3.750	4.57	.30
-49.53	-3.250	6.10	.40
-45.72	-3.000	7.62	.50
-41.91	-2.750	10.67	.70
-38.10	-2.500	15.24	1.00
-34.29	-2.500	22.86	1.50
-30.48	-2.000	30.48	2.00
-26.67	-1.750	38.10	2.50
-22.86	-1.500	45.72	3.00
-19.05	-1.250		
-15.24	-1.000		
-11.43	-0.750		
-6.35	-0.417		
-3.81	-0.250		
-1.27	-0.083		
-0.38	-0.002		



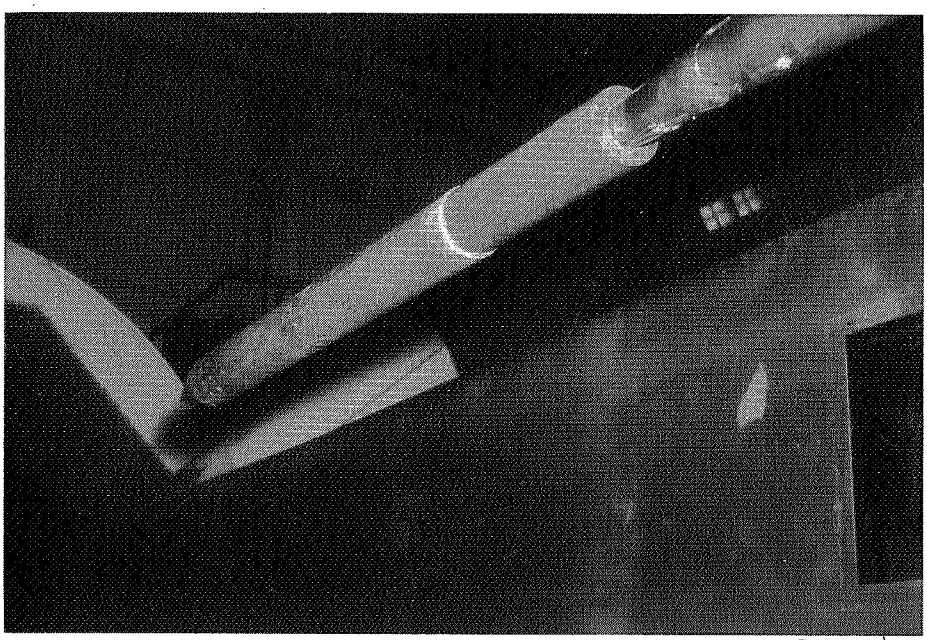
d	d/d_m
9.65	0.63
12.19	.80
13.97	.92
14.48	.95
15.24	1.00

Figure 1.- Details of model. All dimensions in centimeters unless otherwise noted.



L-70-2422

(a) Front view.



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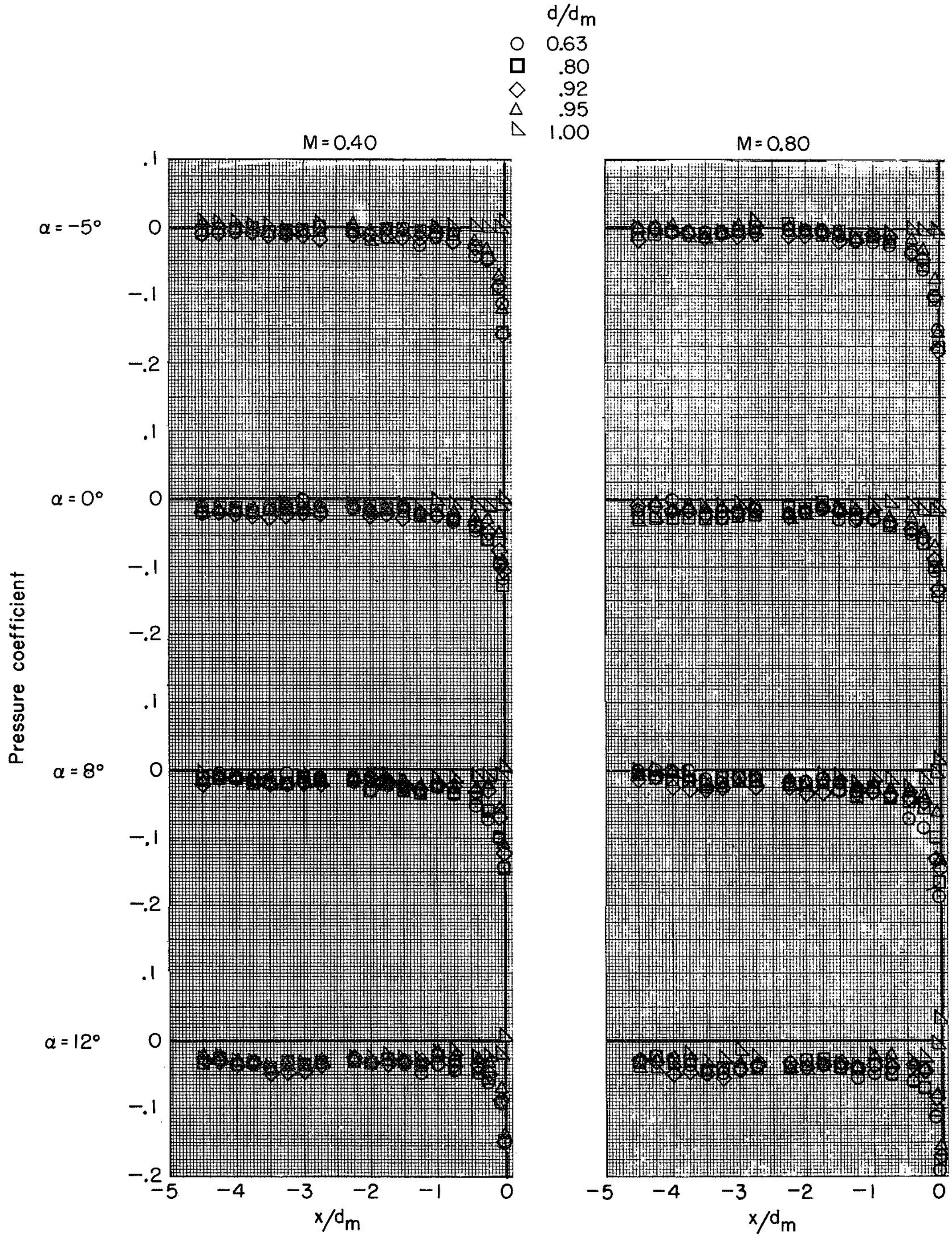
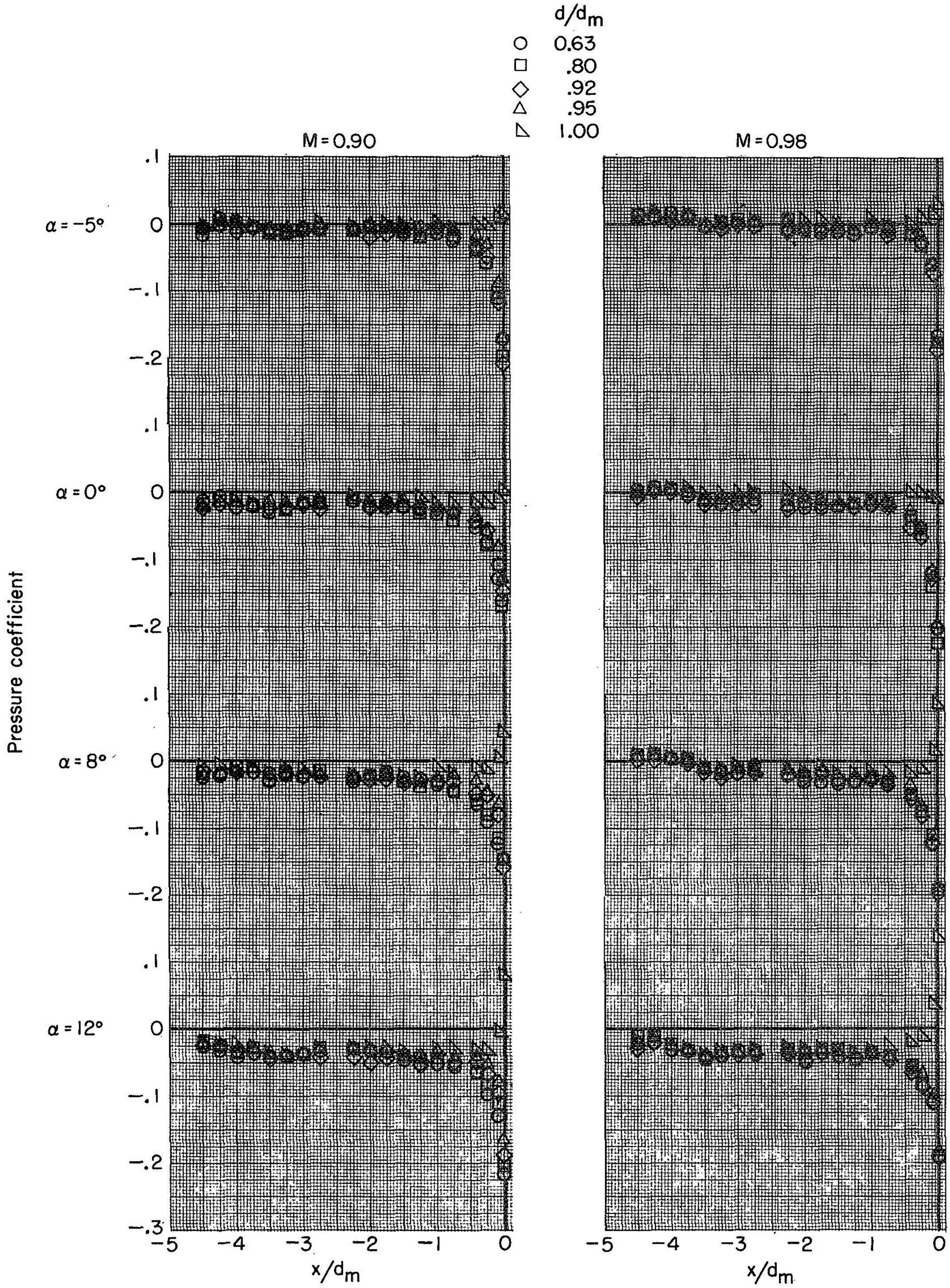
(b) Rear view.

Figure 2.- Photographs of model.



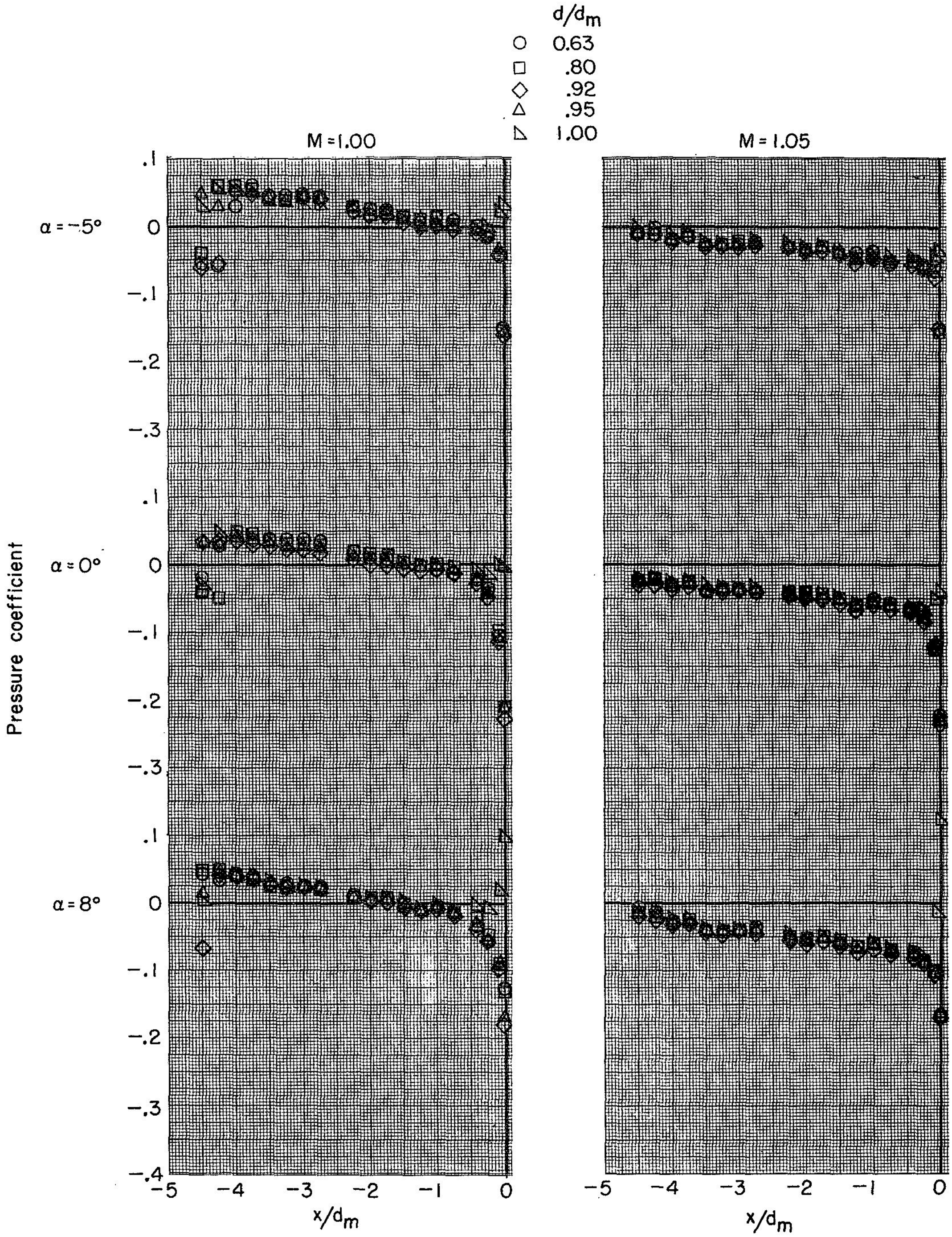
(a) M = 0.40 and 0.80.

Figure 3.- Typical pressure distributions at $\phi = 0^{\circ}$ on cylindrical surface ahead of three-dimensional step.



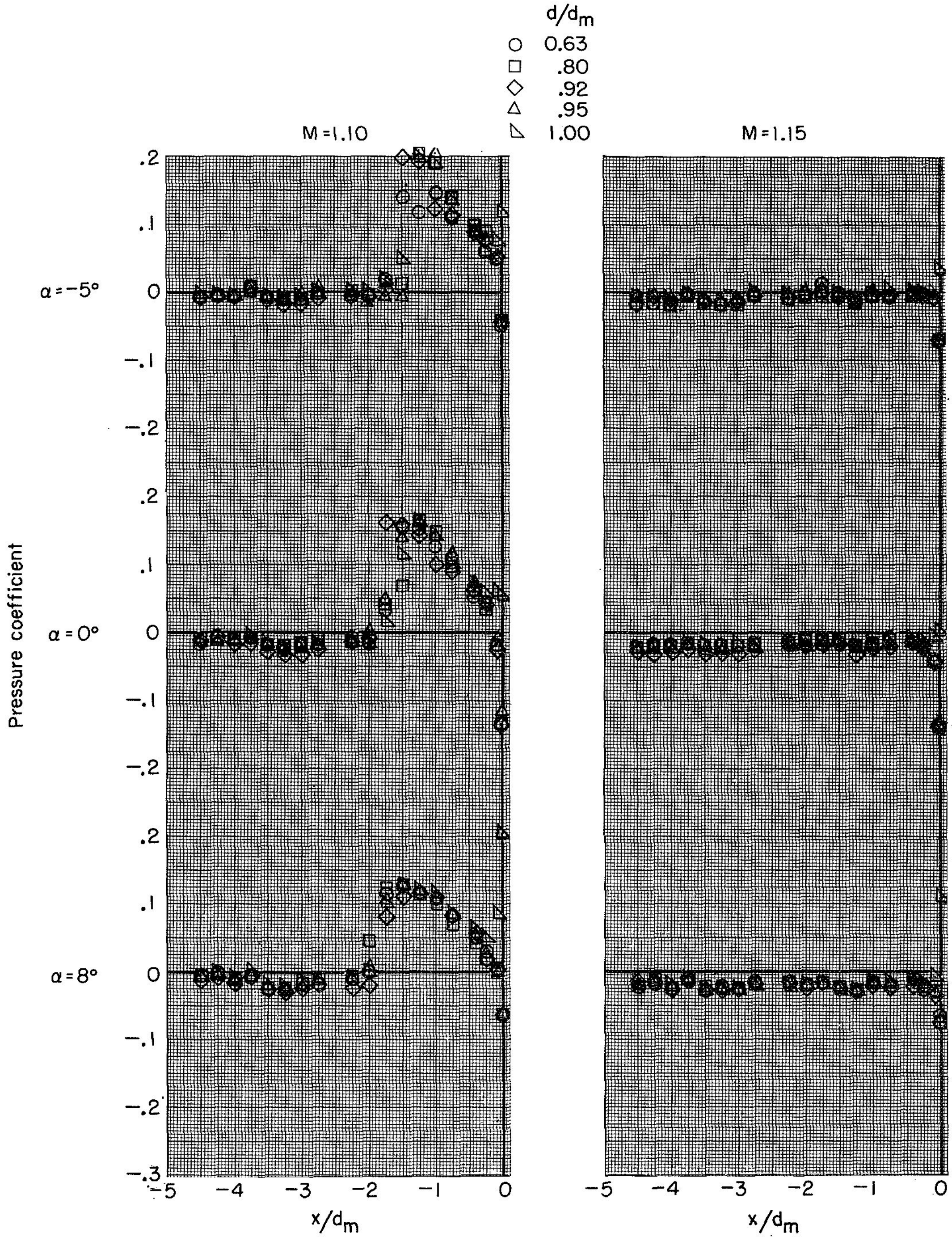
(b) M = 0.90 and 0.98.

Figure 3.- Continued.



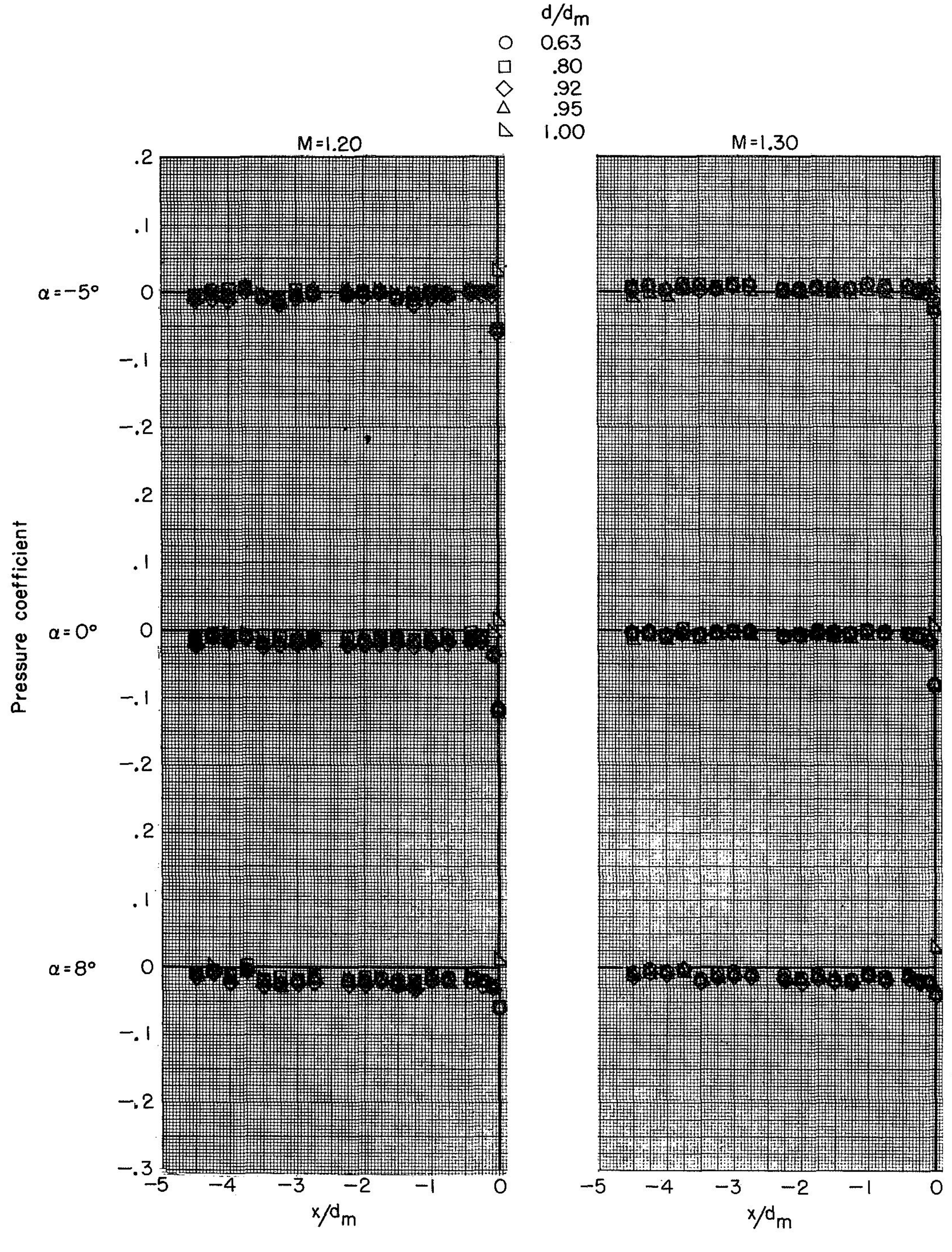
(c) M = 1.00 and 1.05.

Figure 3.- Continued.



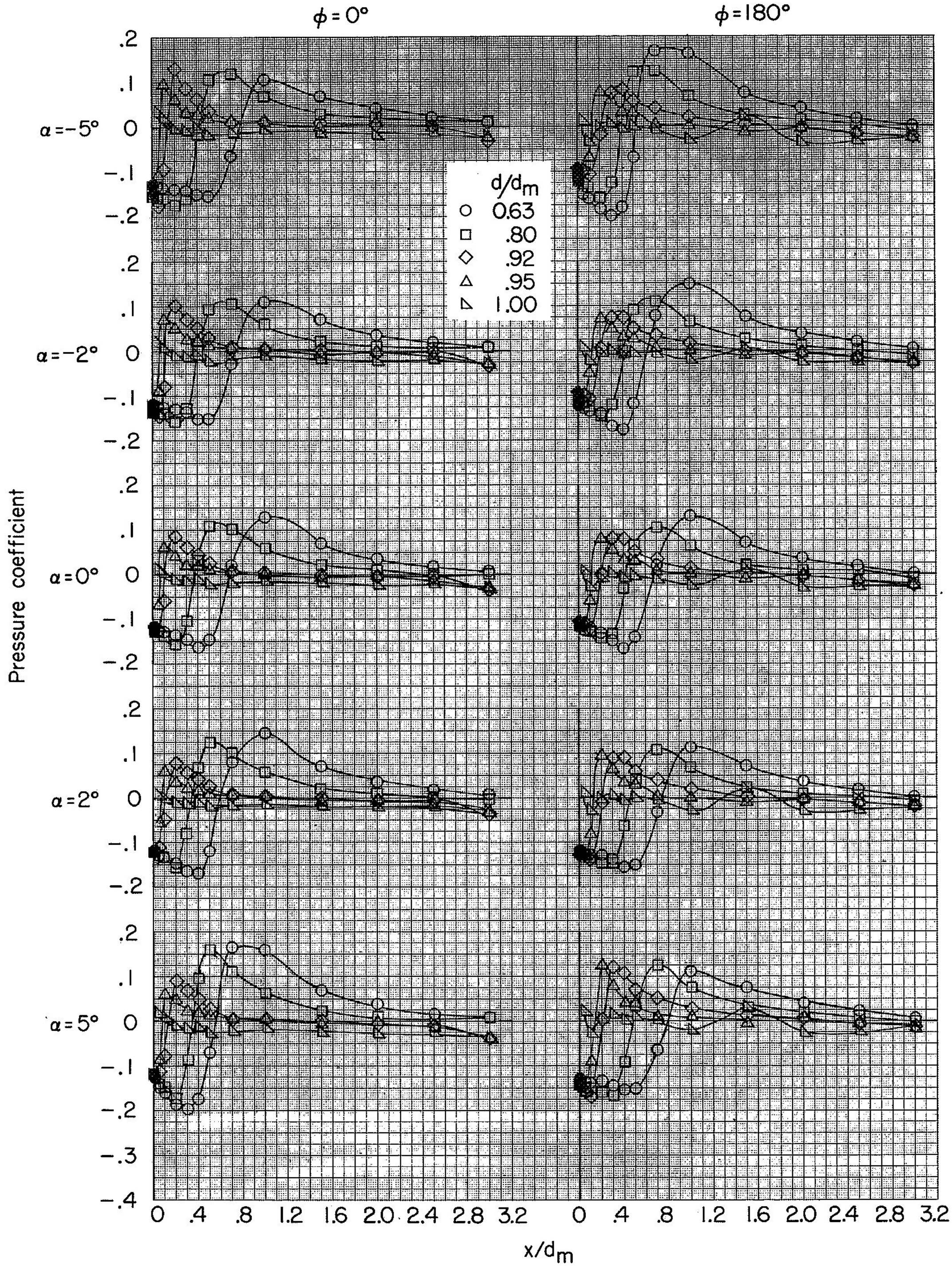
(d) M = 1.10 and 1.15.

Figure 3.- Continued.



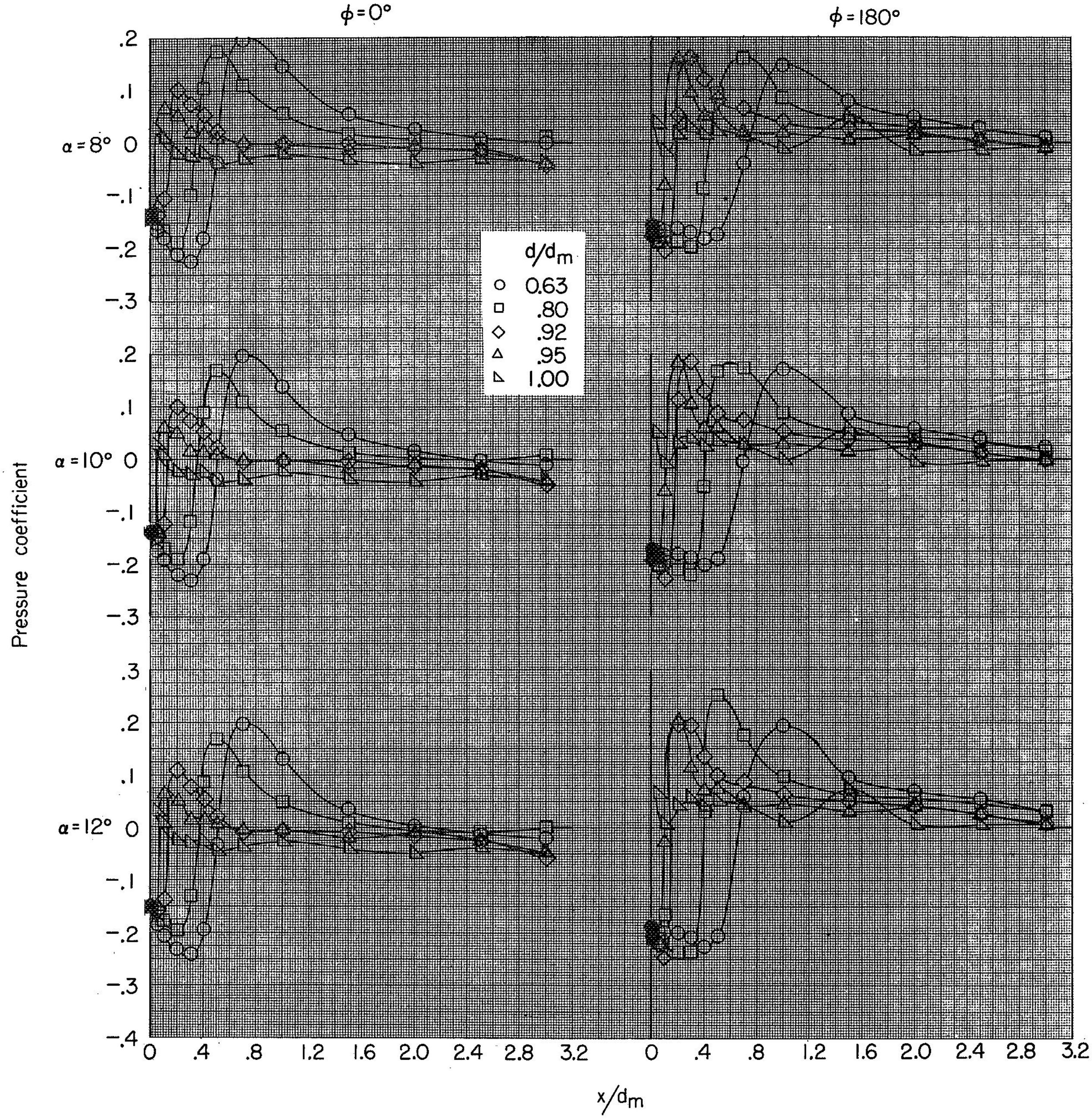
(e) M = 1.20 and 1.30.

Figure 3.- Concluded.



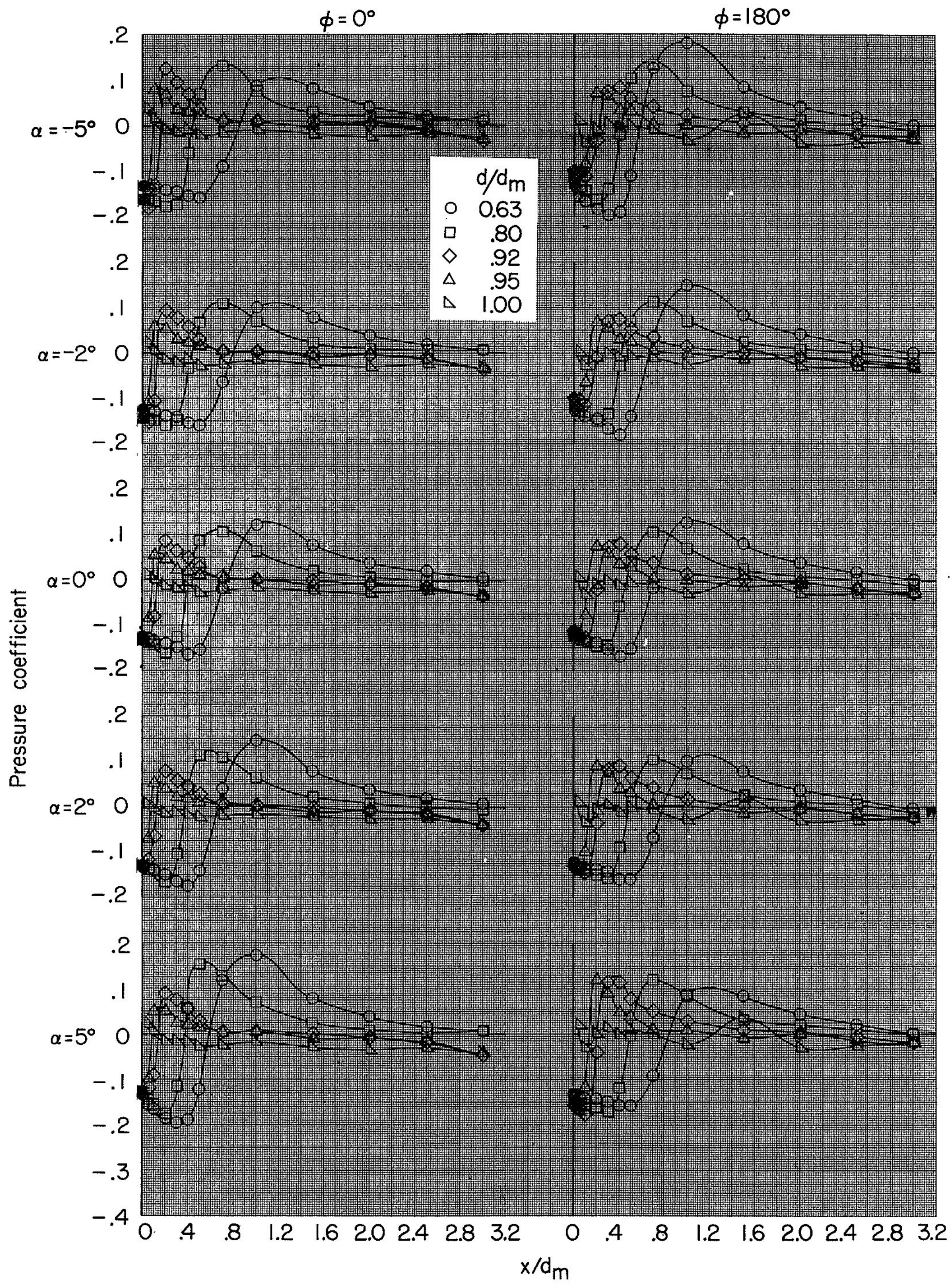
(a) M = 0.40.

Figure 4.- Pressure distributions on cylindrical surface behind three-dimensional step. Solid symbols indicate step base pressure coefficient.



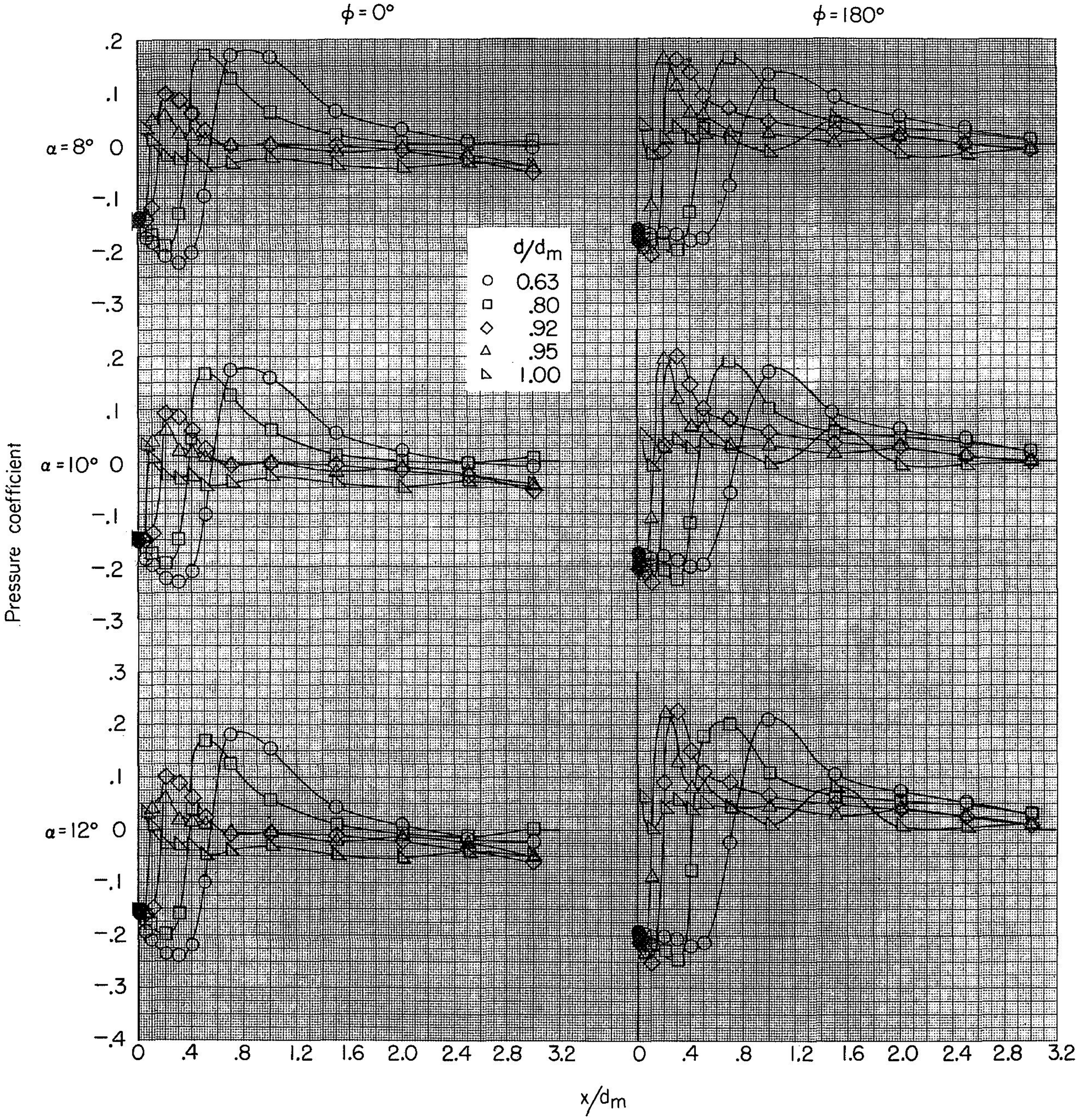
(a) M = 0.40. Concluded.

Figure 4.- Continued.



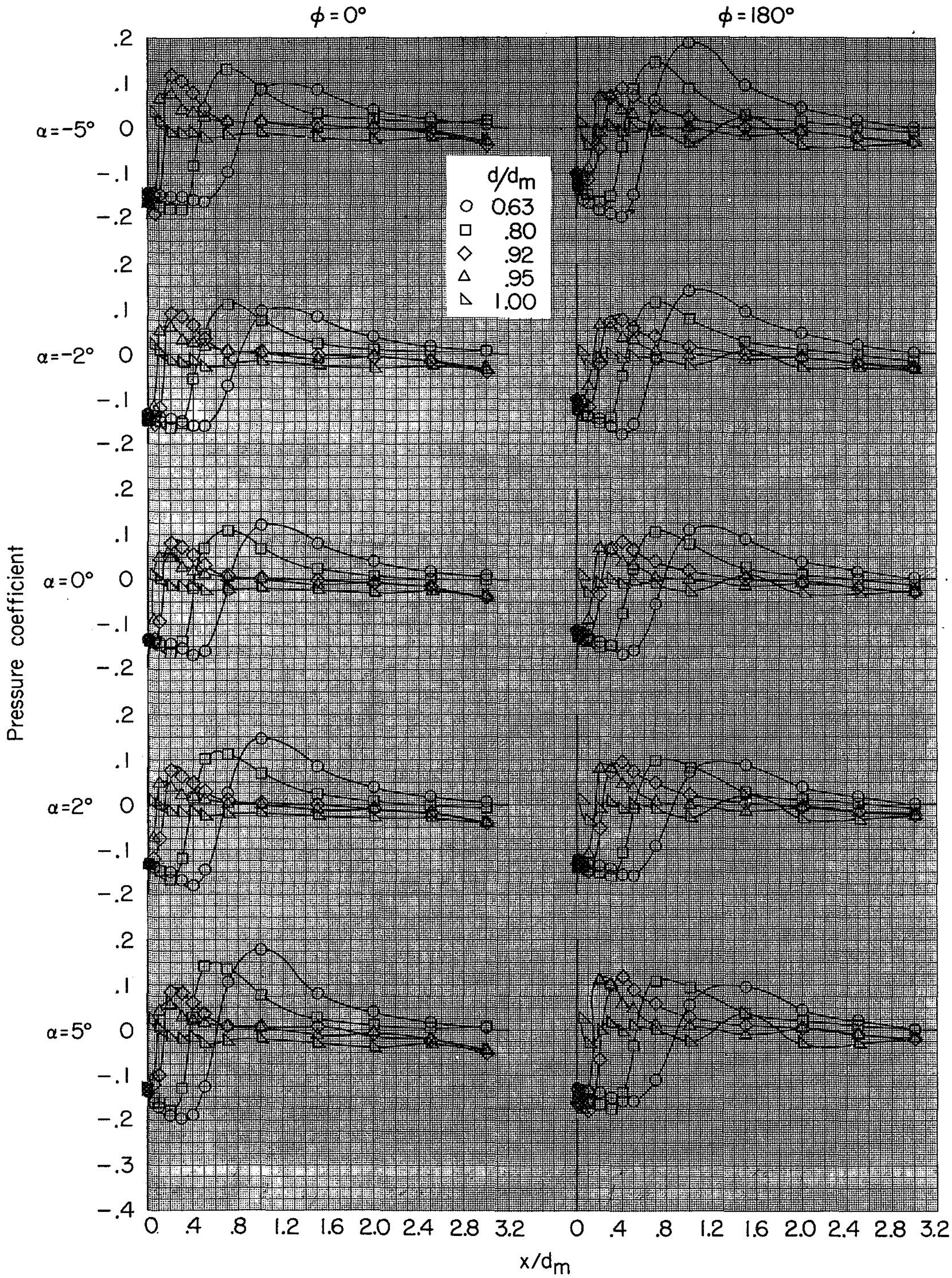
(b) M = 0.60.

Figure 4.- Continued.



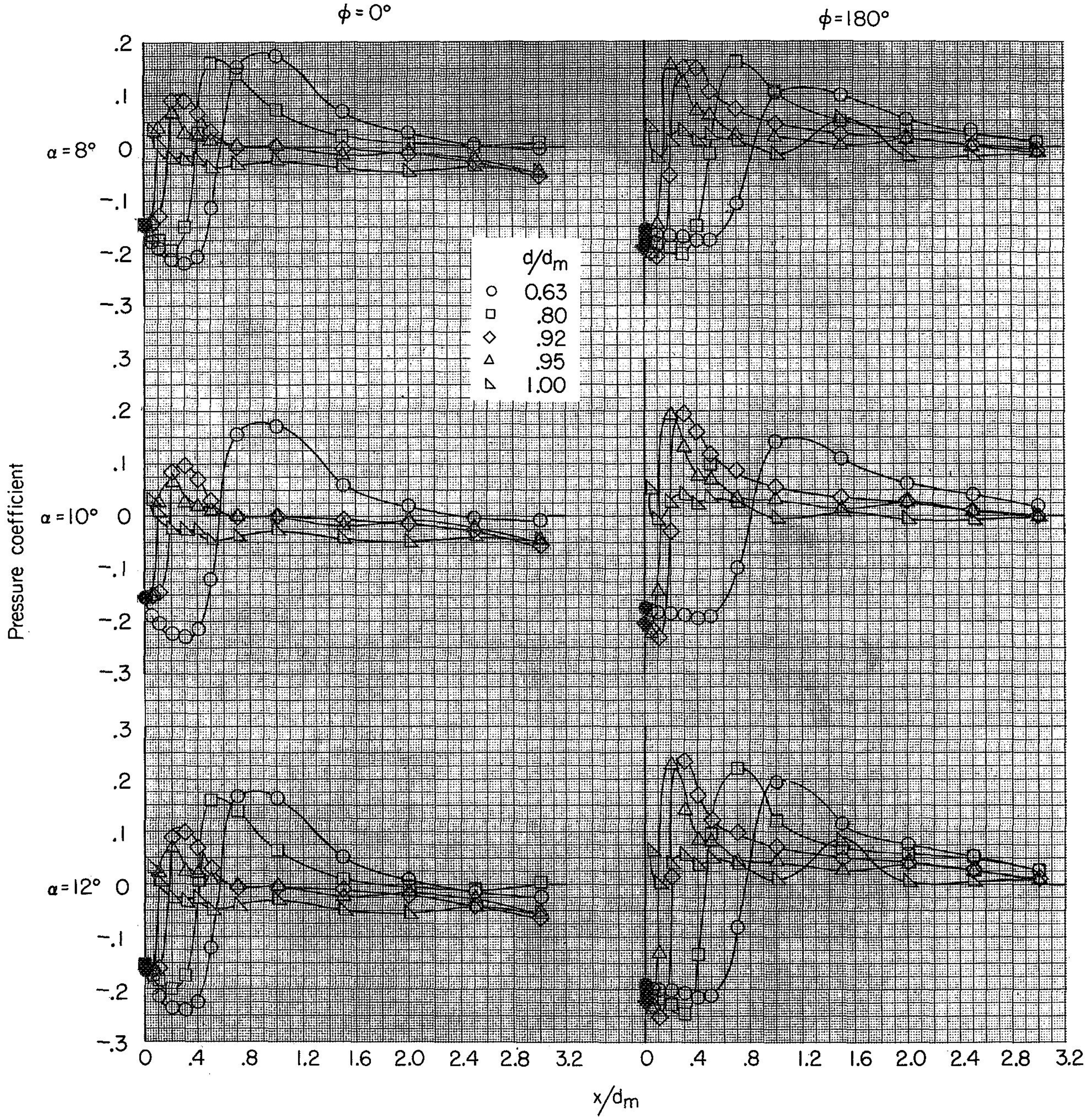
(b) M = 0.60. Concluded.

Figure 4.- Continued.



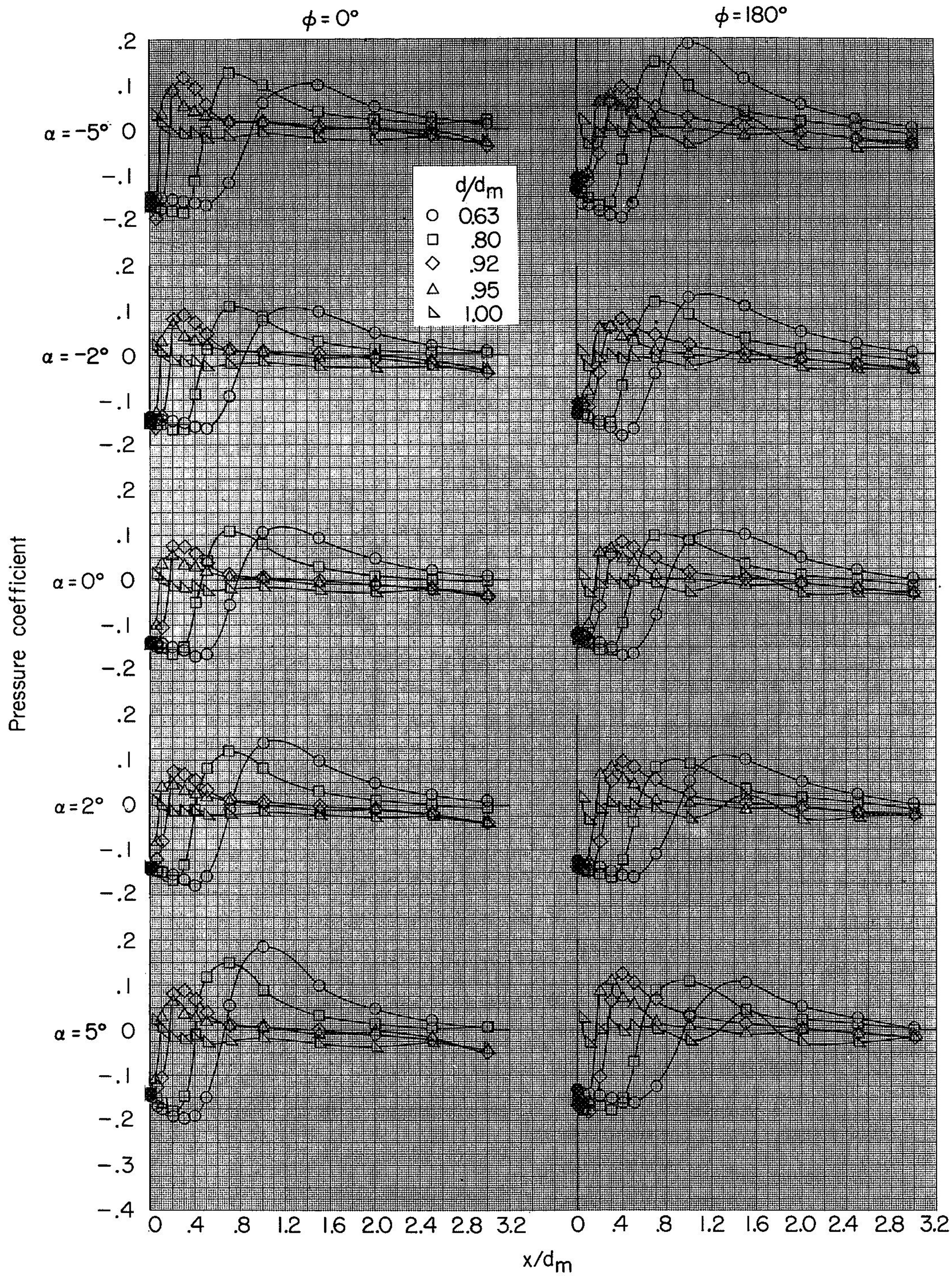
(c) M = 0.70.

Figure 4.- Continued.



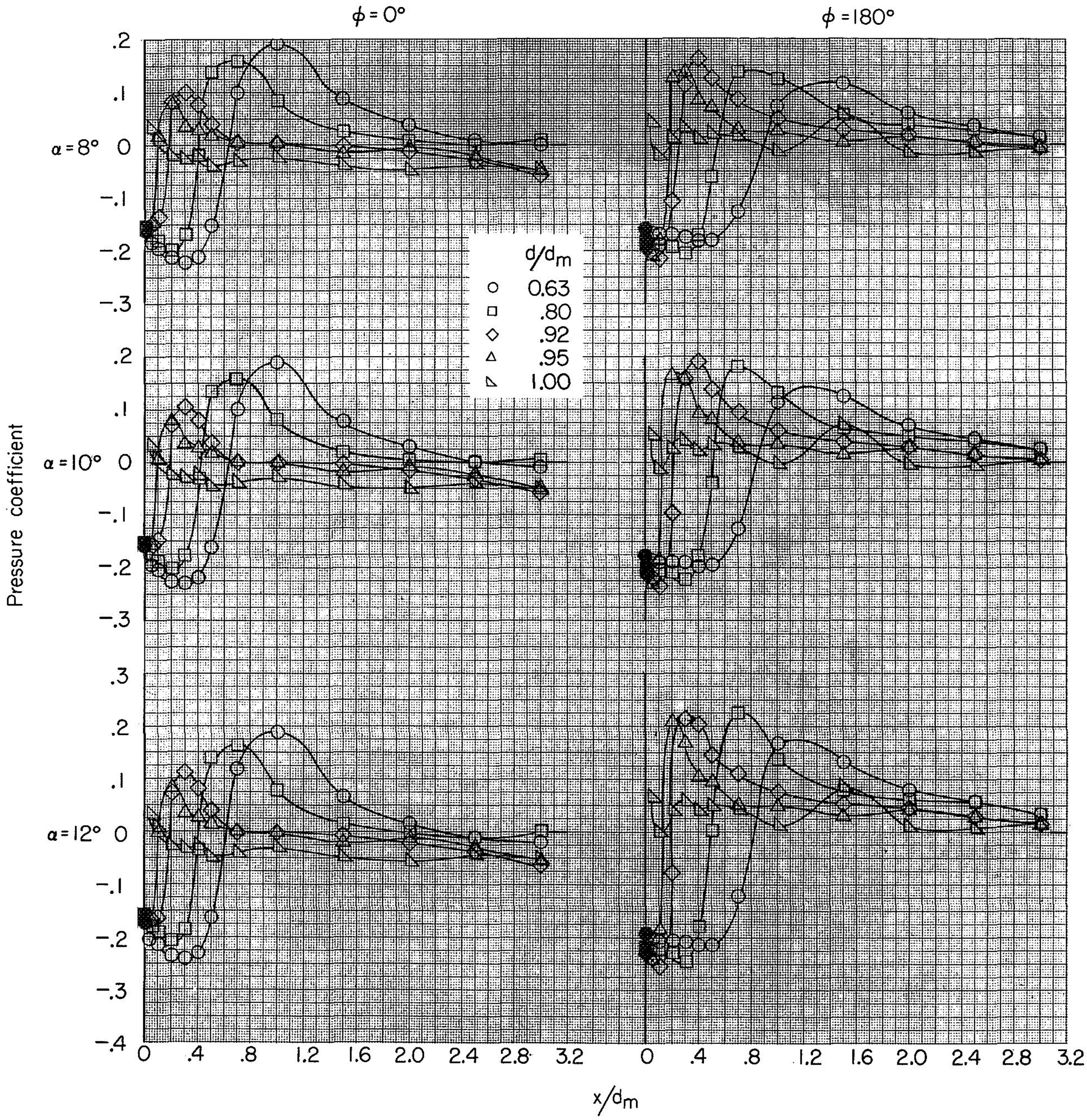
(c) M = 0.70. Concluded.

Figure 4.- Continued.



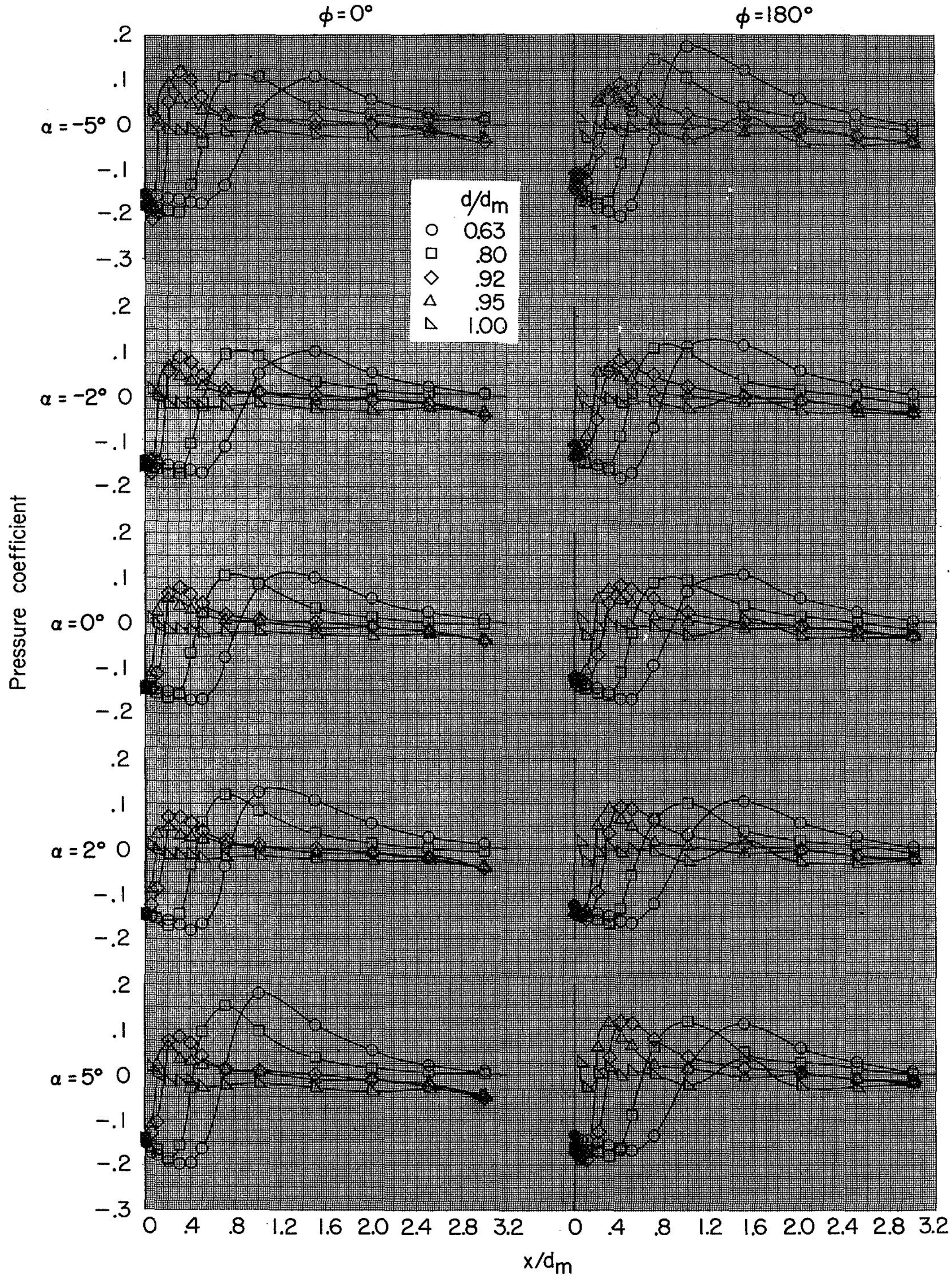
(d) M = 0.80.

Figure 4.- Continued.



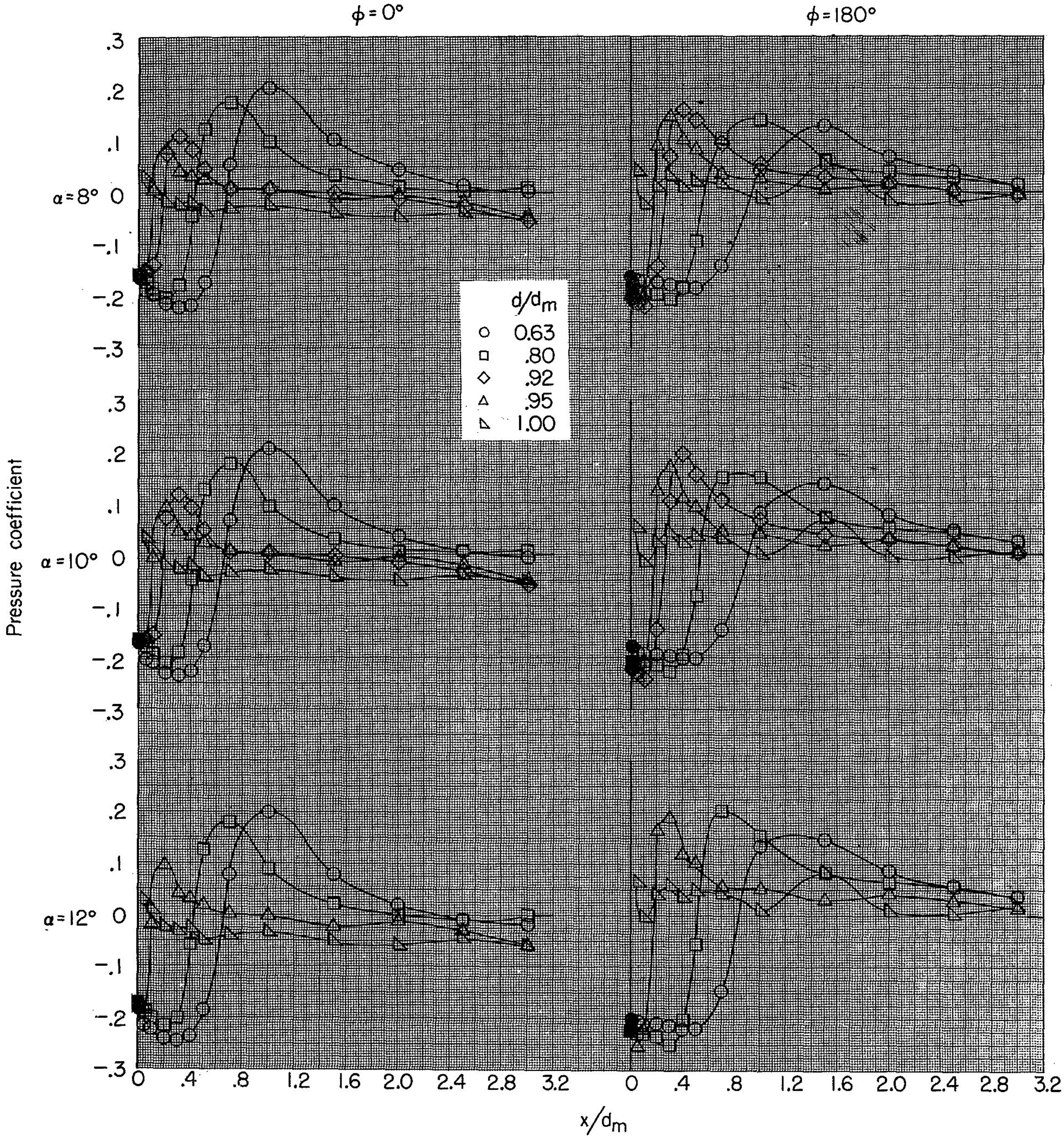
(d) M = 0.80. Concluded.

Figure 4.- Continued.



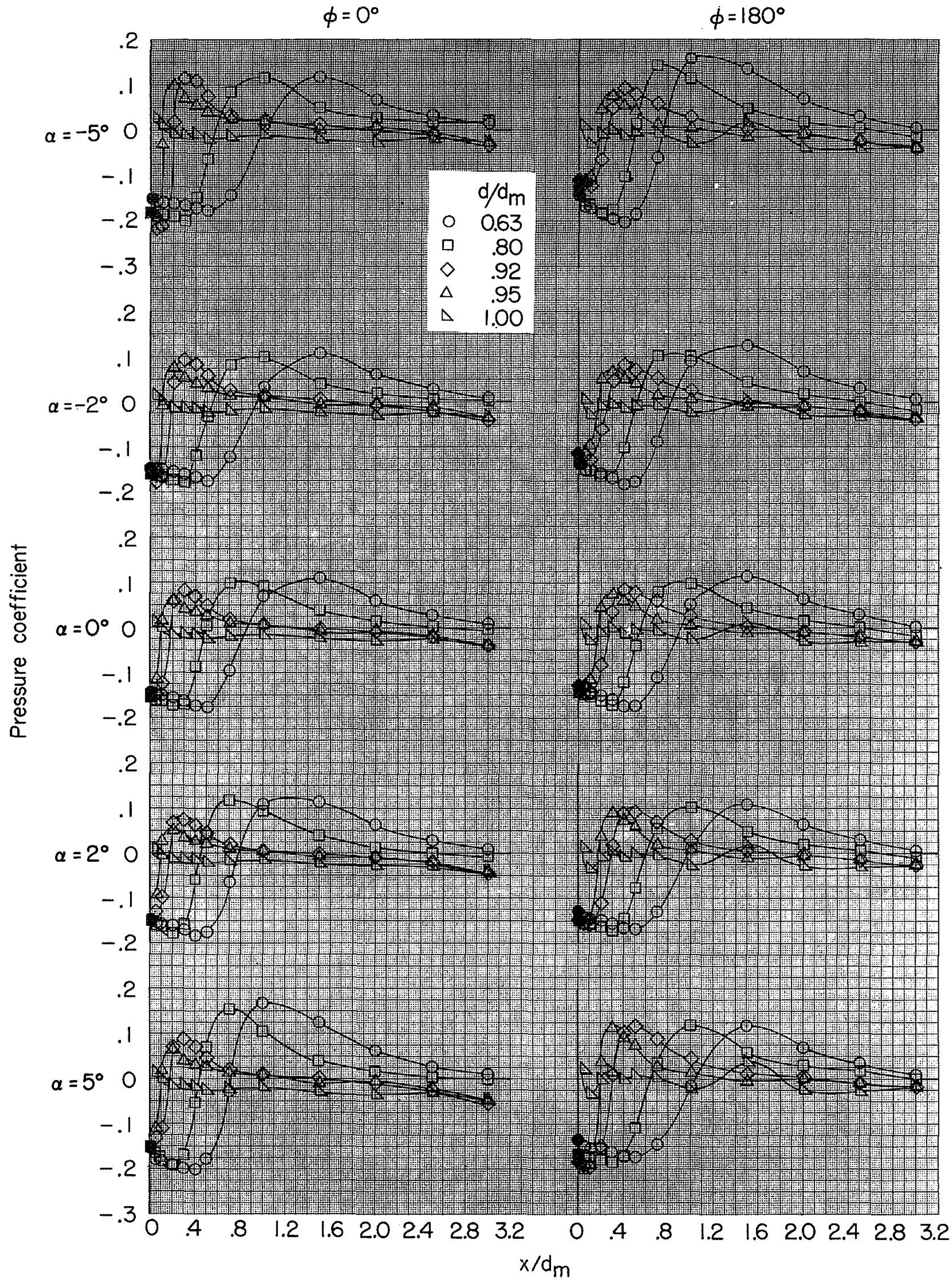
(e) M = 0.86.

Figure 4.- Continued.



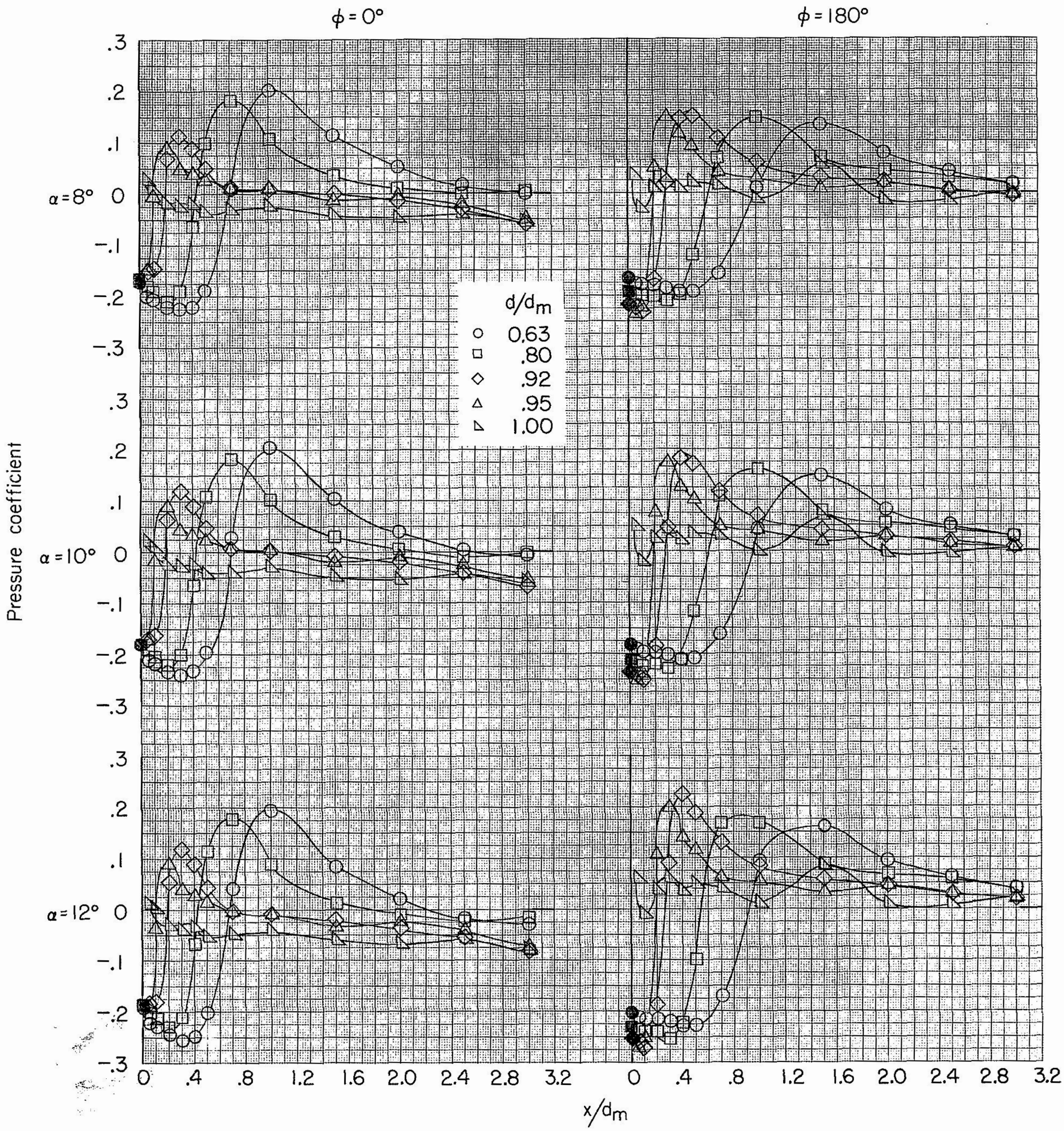
(e) M = 0.86. Concluded.

Figure 4.- Continued.



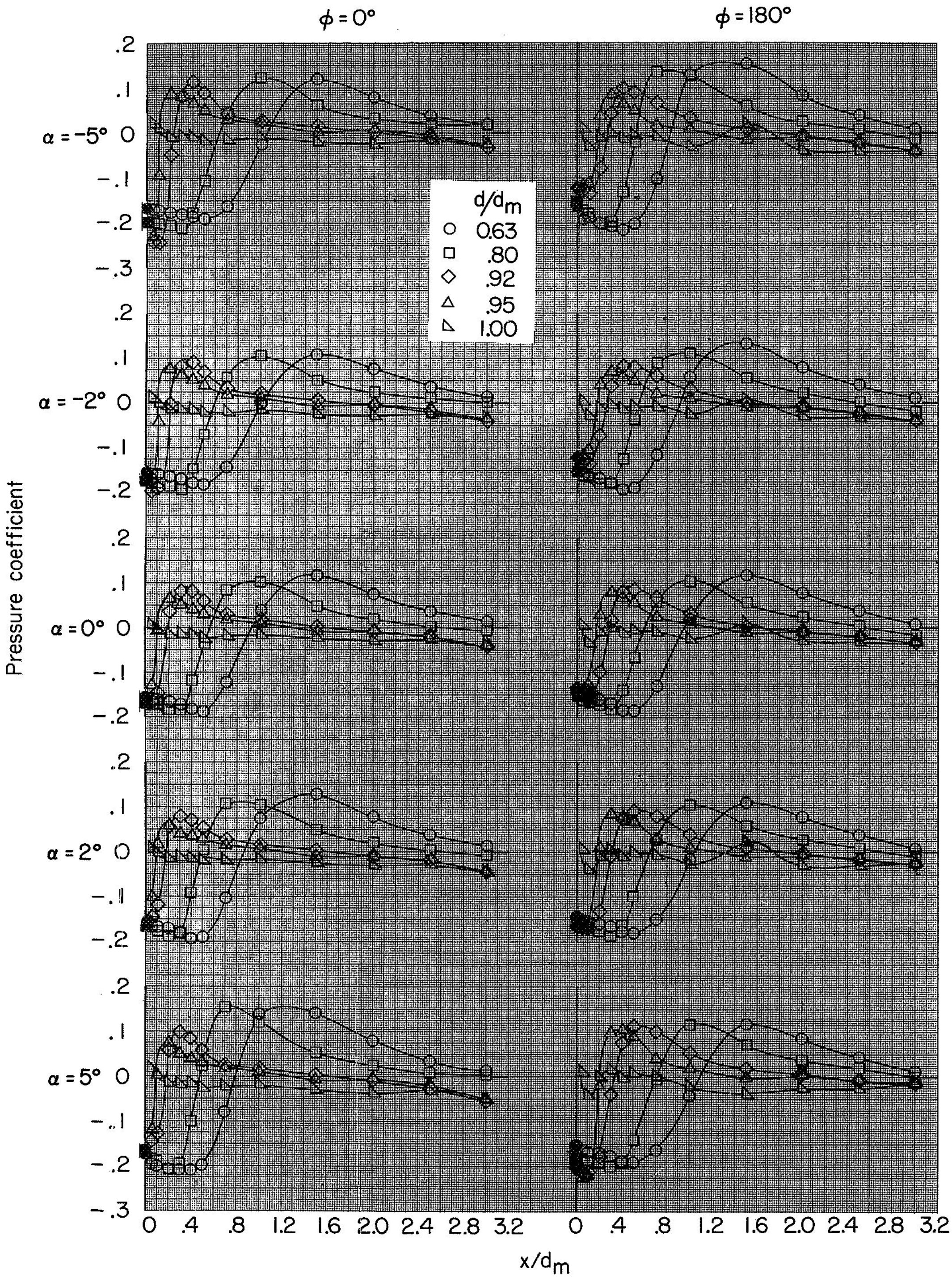
(f) M = 0.90.

Figure 4.- Continued.



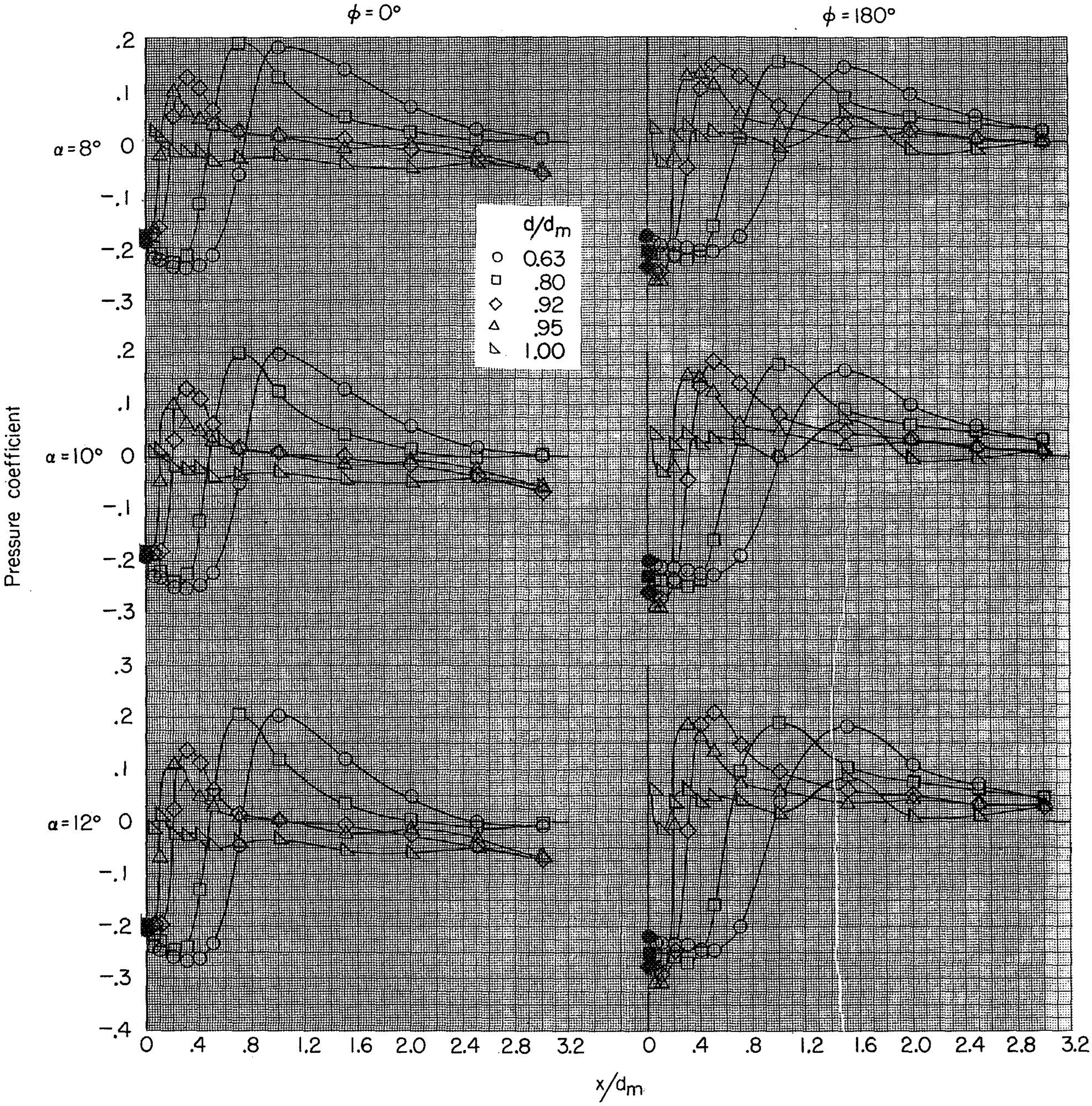
(f) M = 0.90. Concluded.

Figure 4.- Continued.



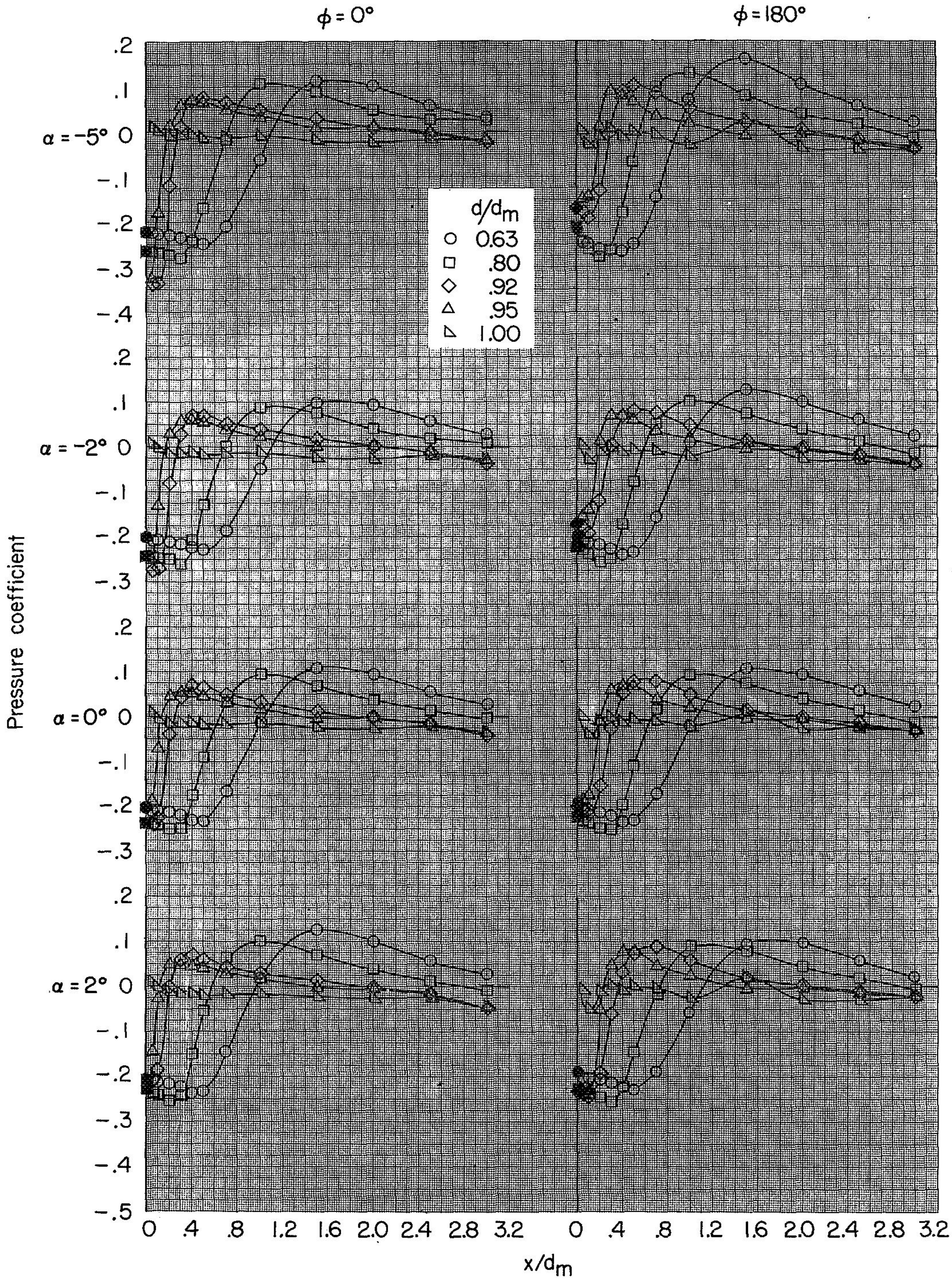
(g) M = 0.94.

Figure 4.- Continued.



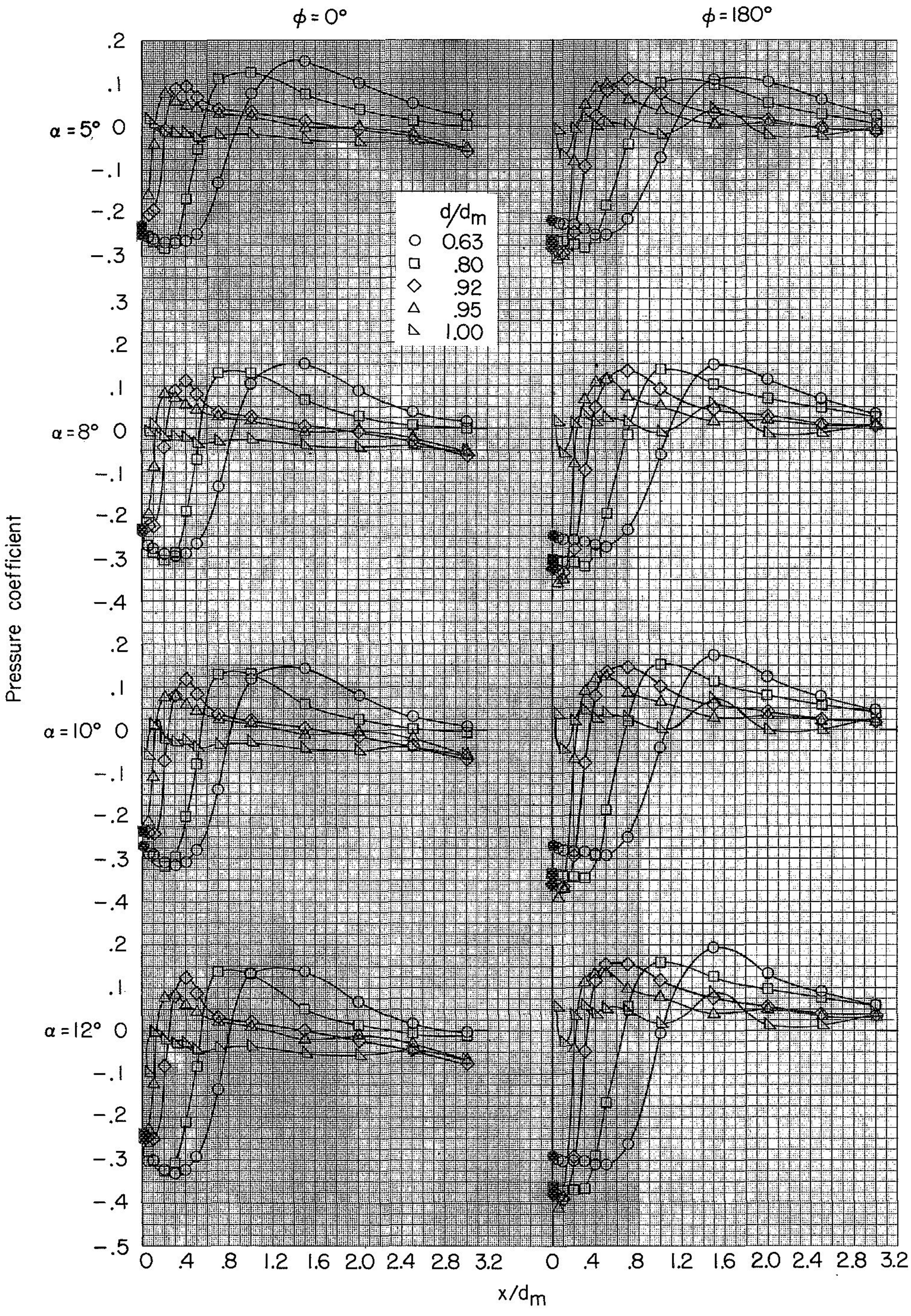
(g) M = 0.94. Concluded.

Figure 4.- Continued.



(h) M = 0.98.

Figure 4.- Continued.



(h) M = 0.98. Concluded.

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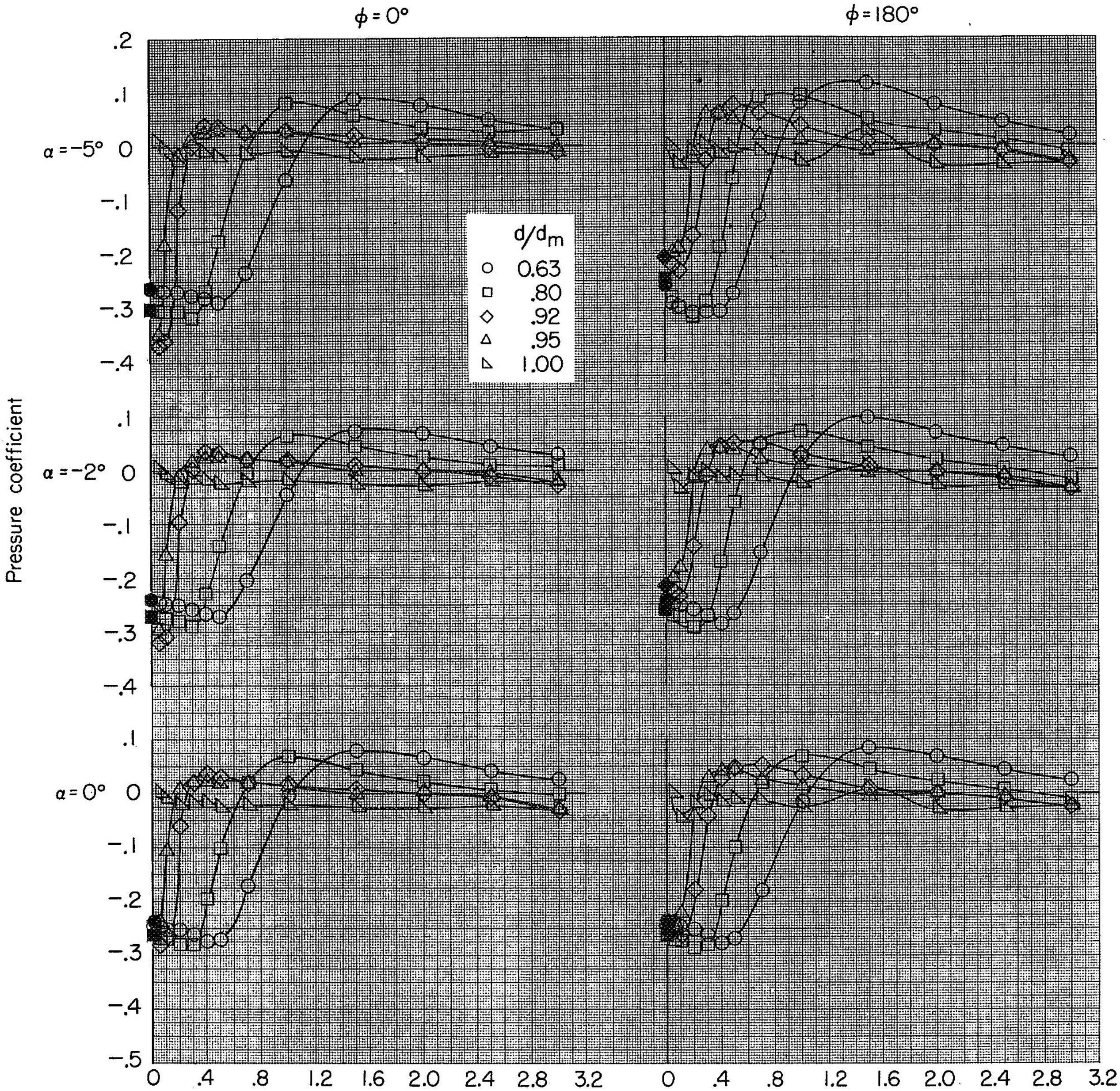
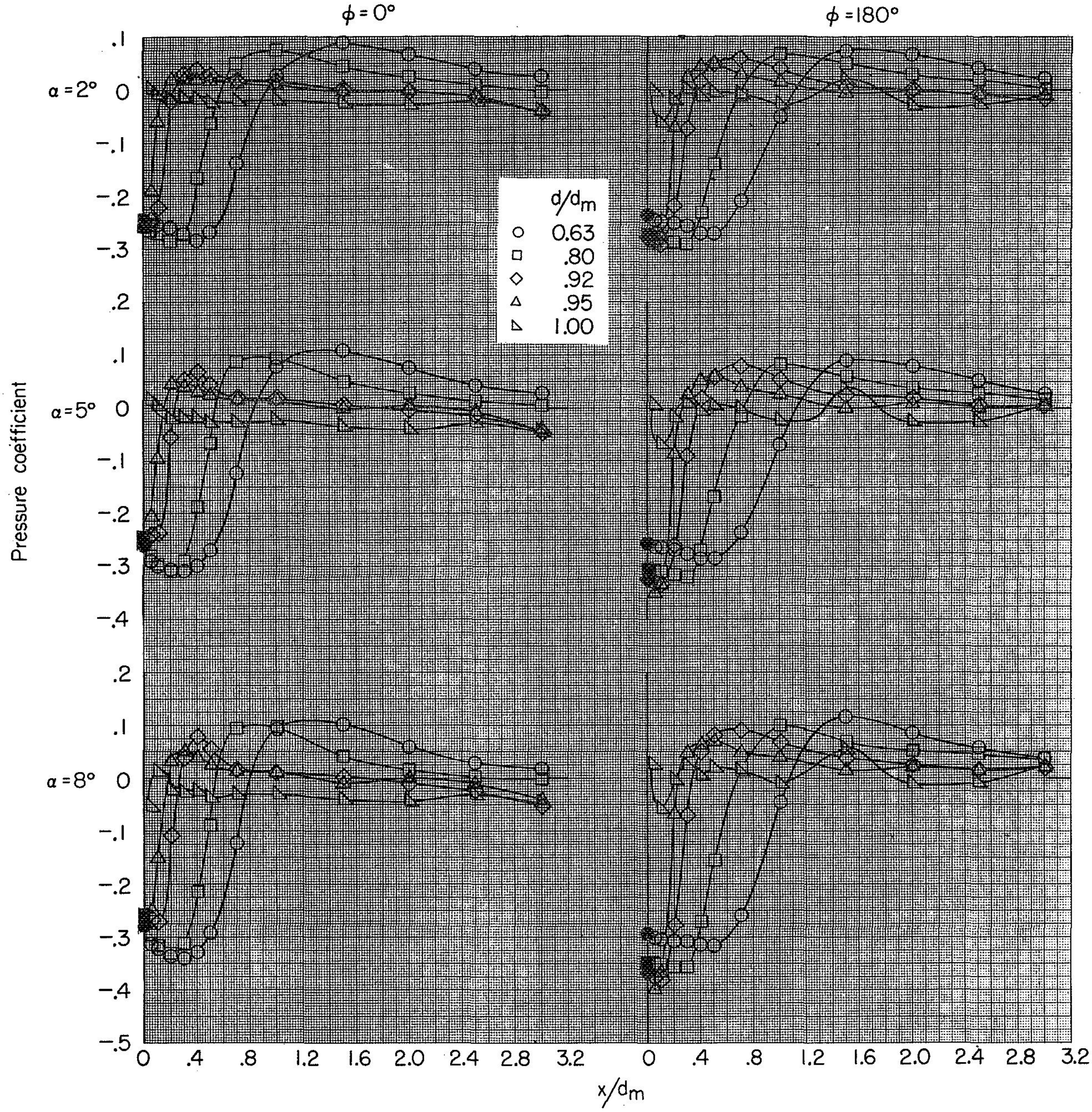


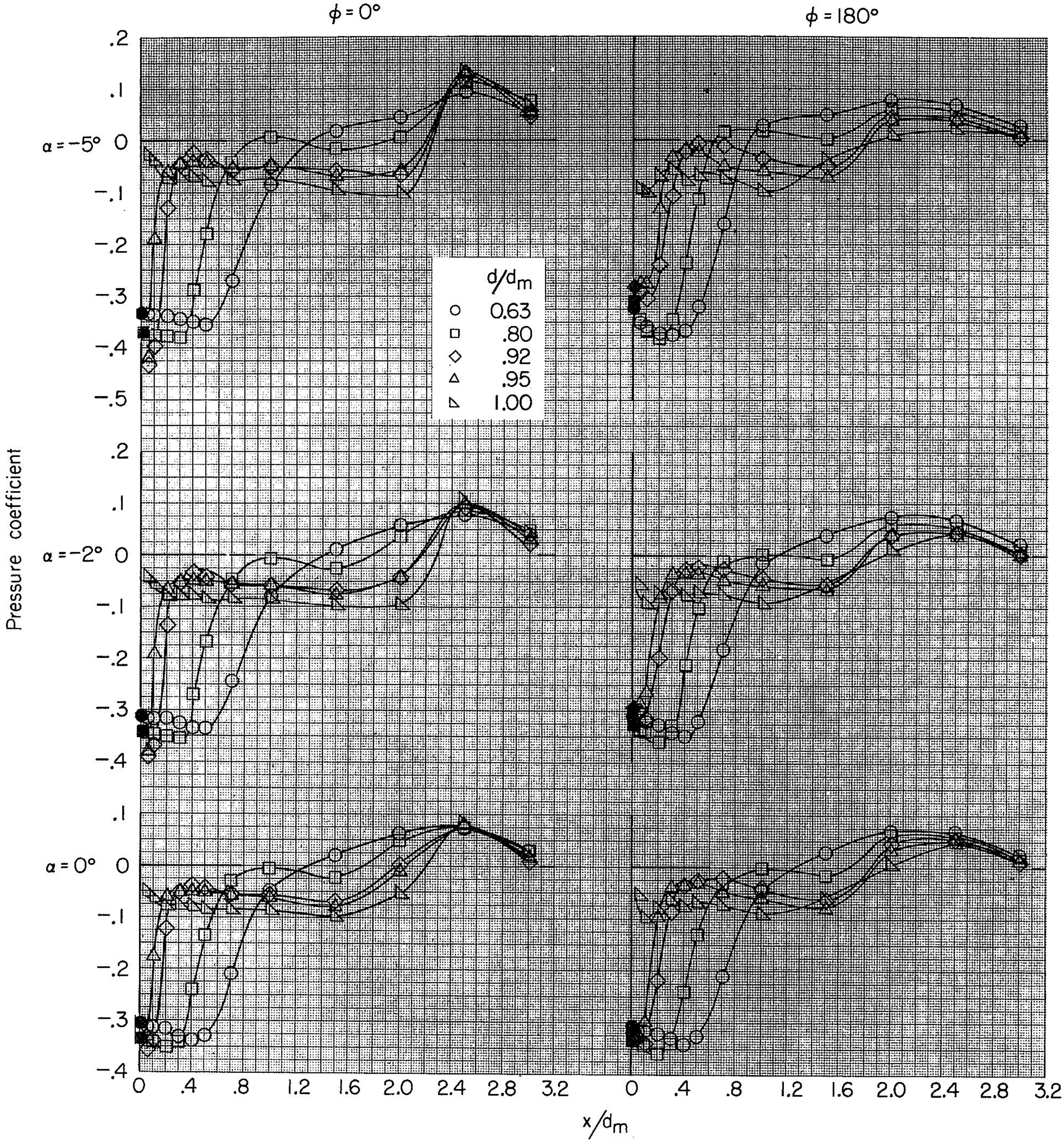
(i) M = 1.00.

Figure 4.- Continued.



(i) M = 1.00. Concluded.

Figure 4.- Continued.



(j) M = 1.05.

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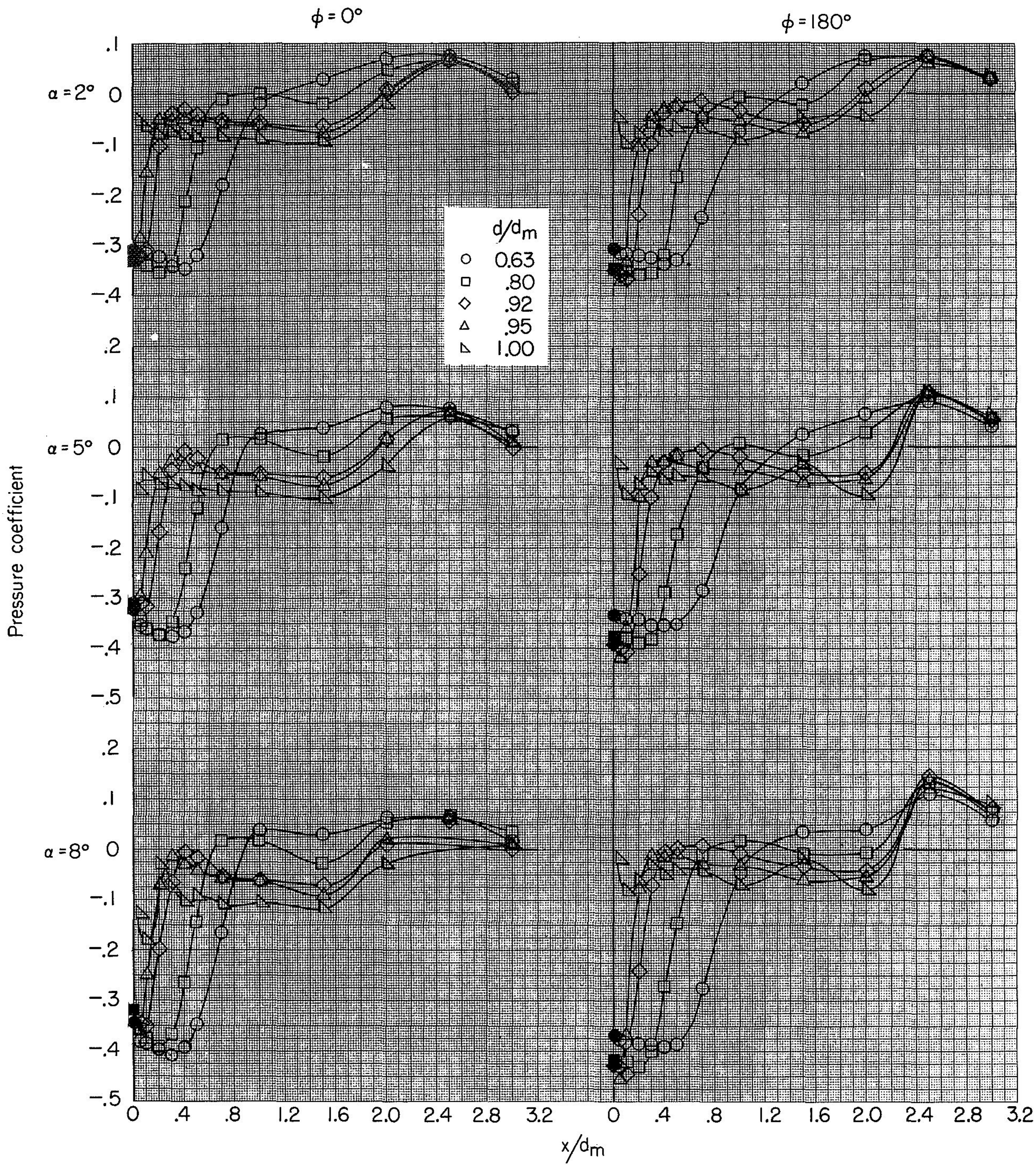

(j) M = 1.05. Concluded.

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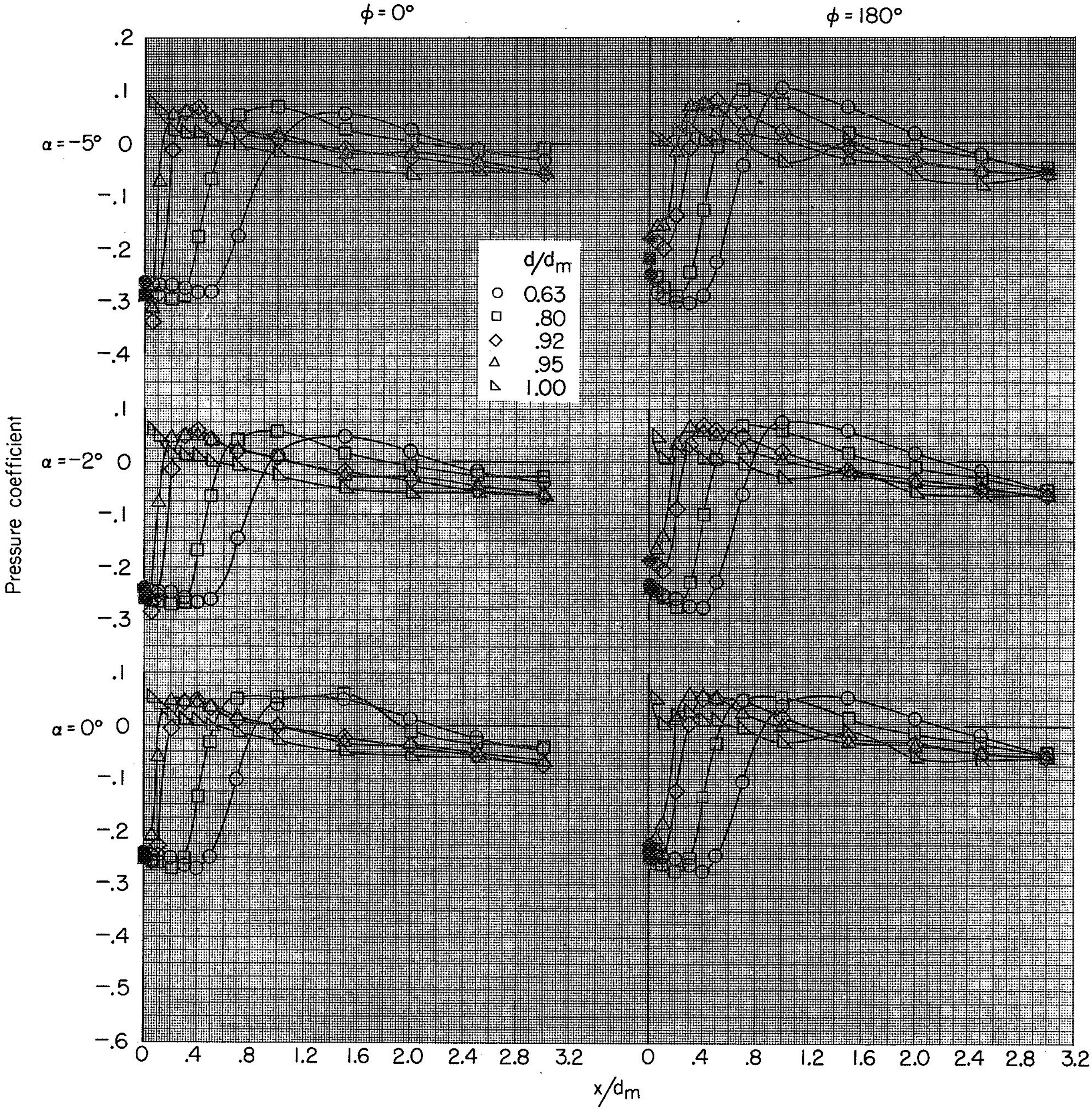

(k) M = 1.10.

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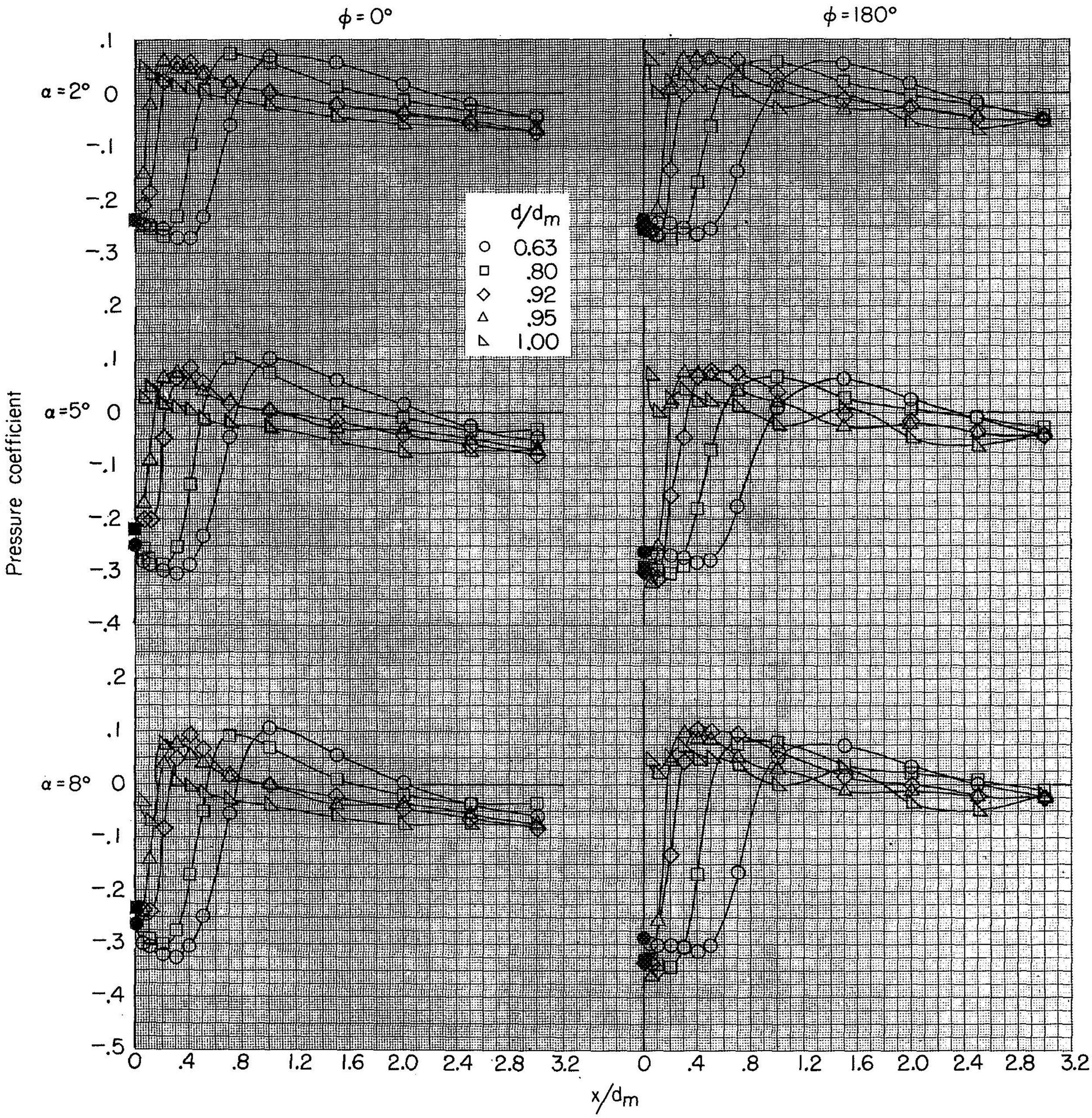
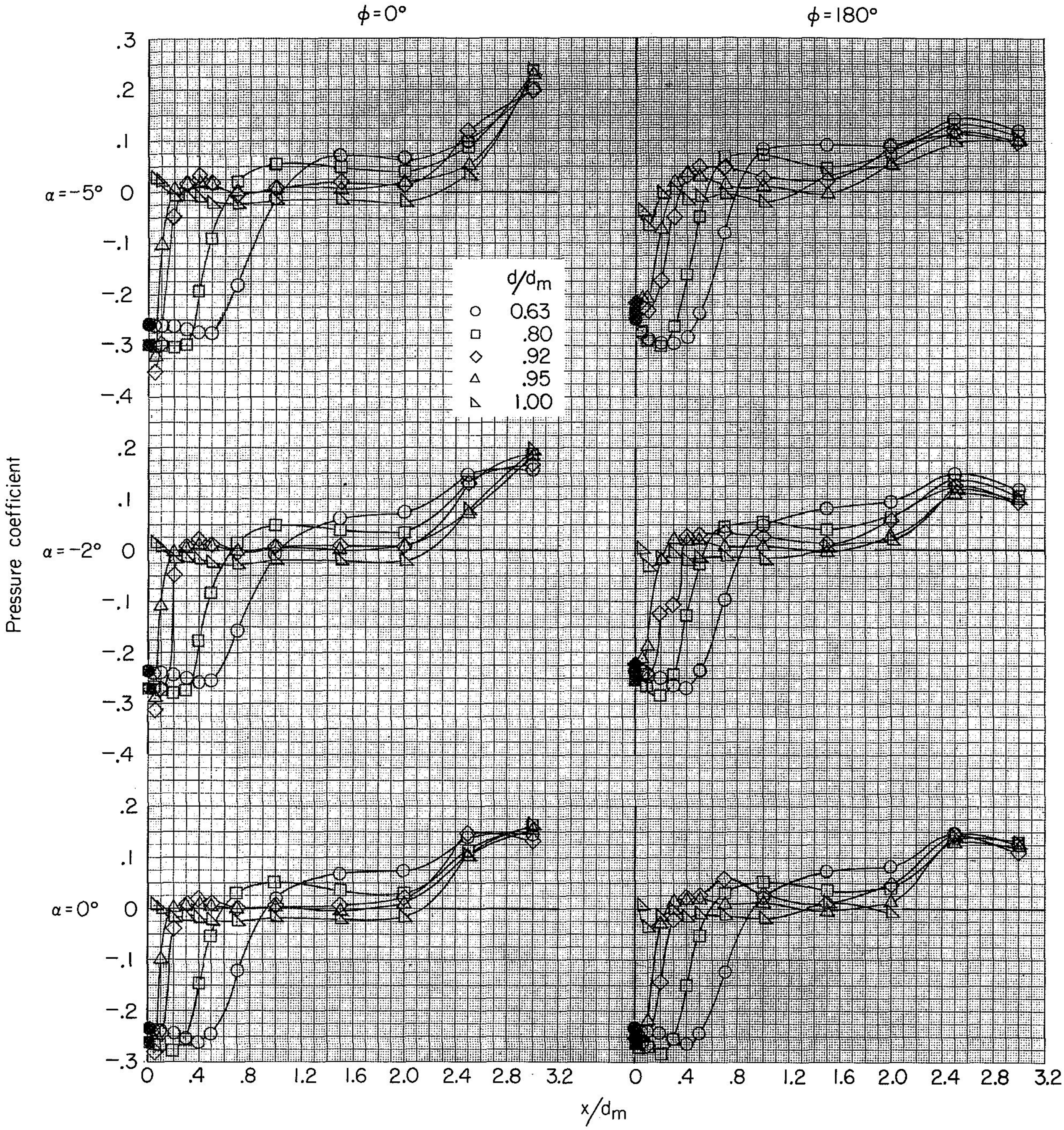


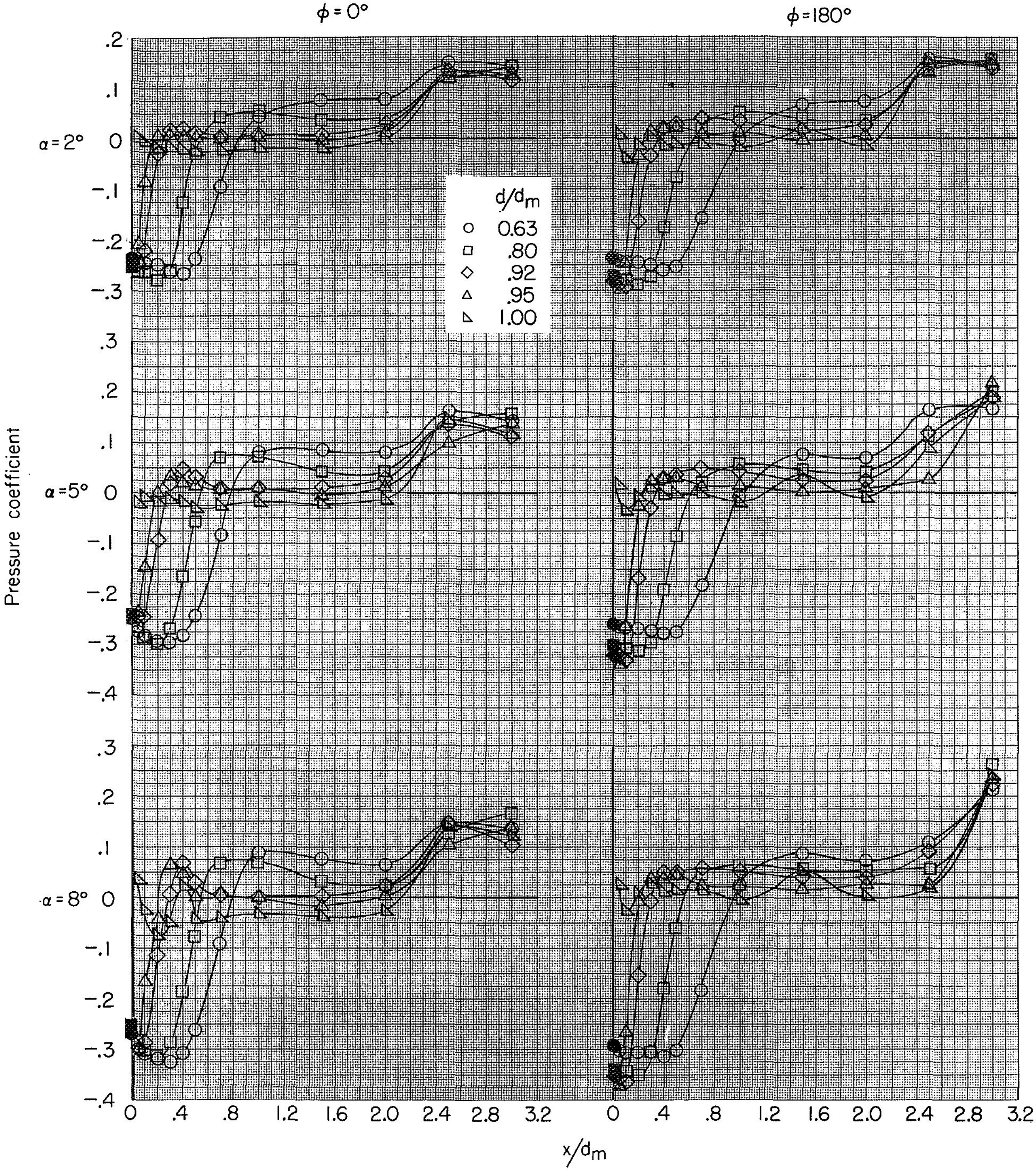
(k) M = 1.10. Concluded.

Figure 4.- Continued.



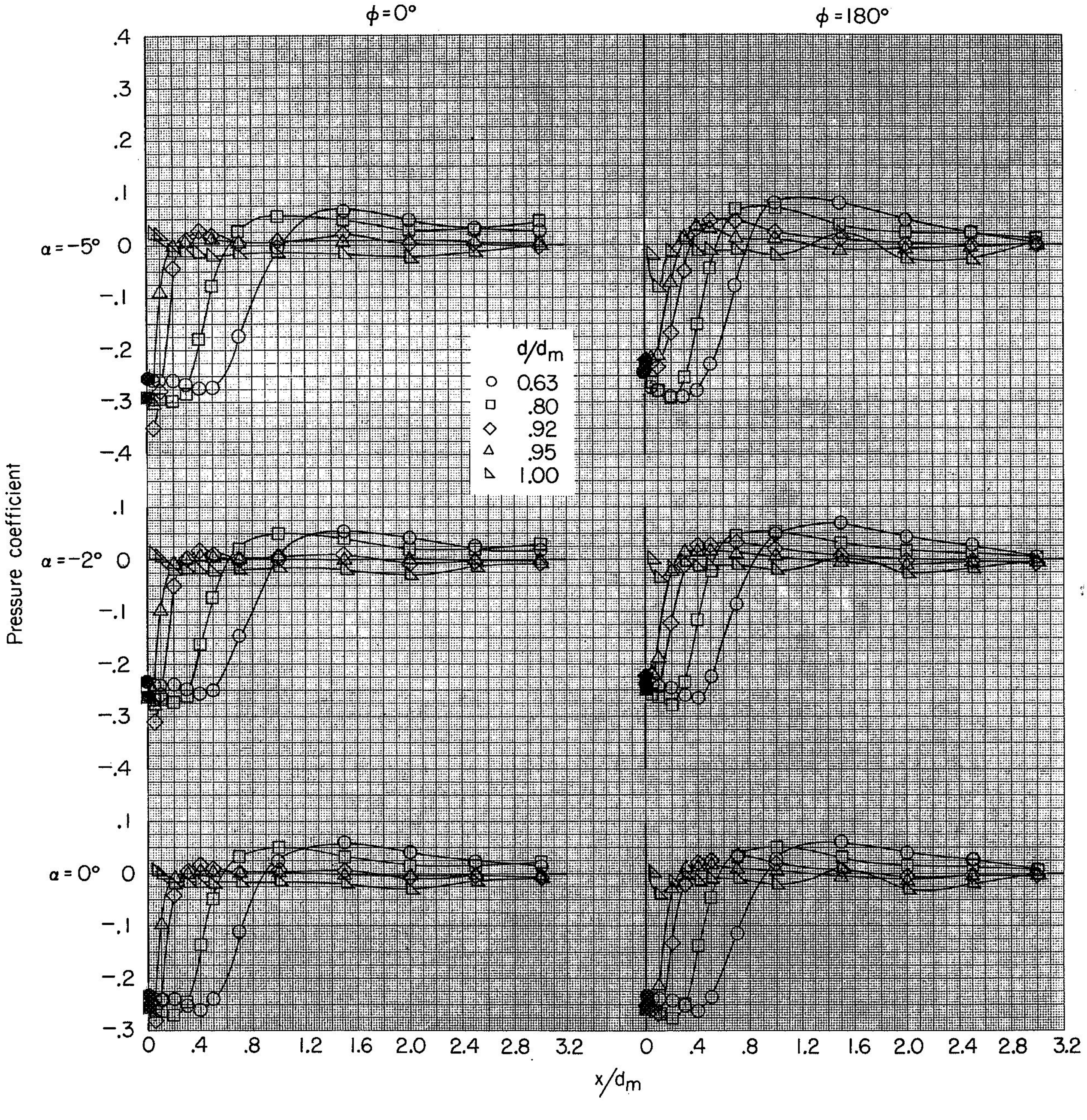
(l) M = 1.15.

Figure 4.- Continued.



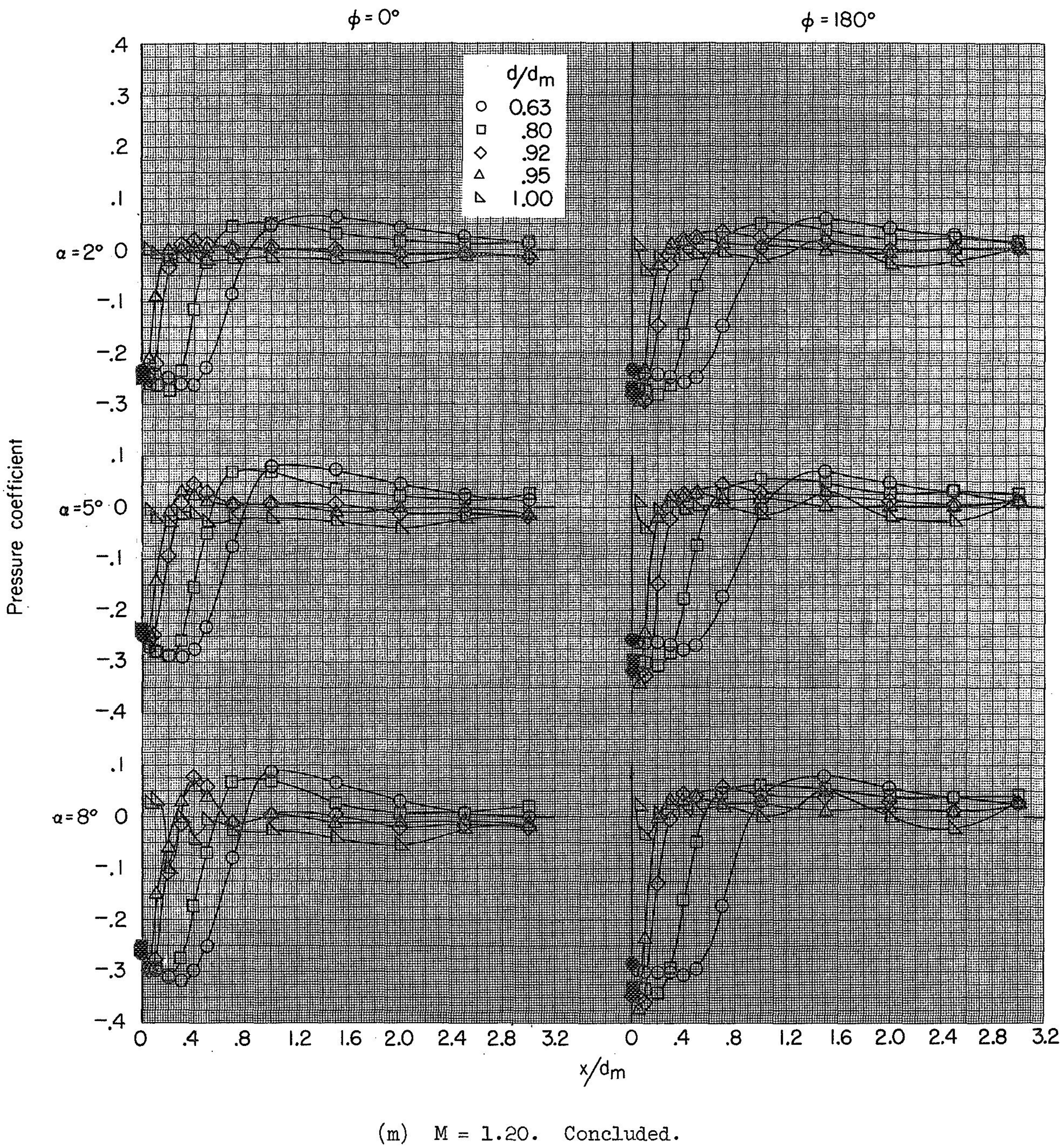
(l) M = 1.15. Concluded.

Figure 4.- Continued.



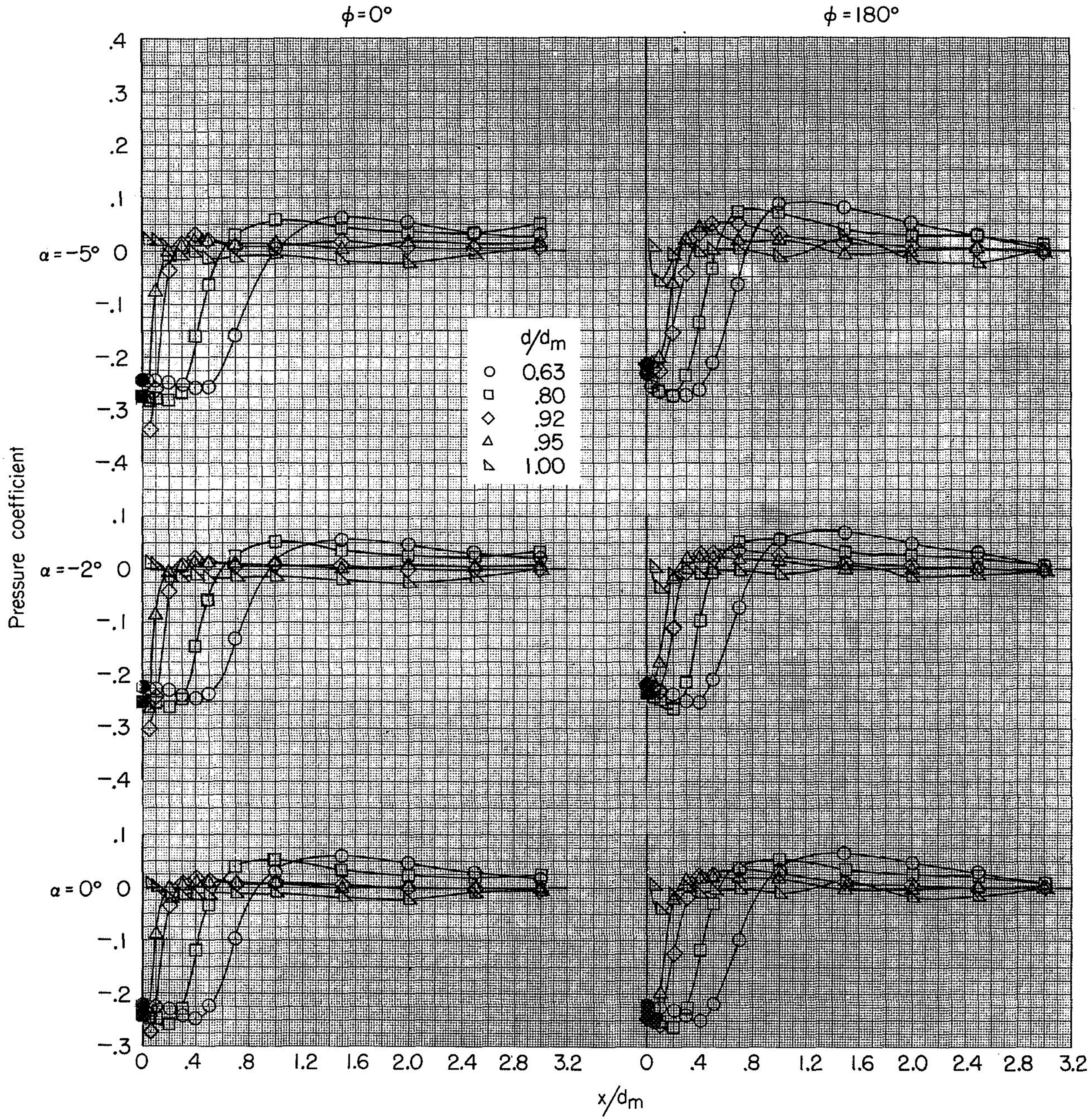
(m) M = 1.20.

Figure 4.- Continued.



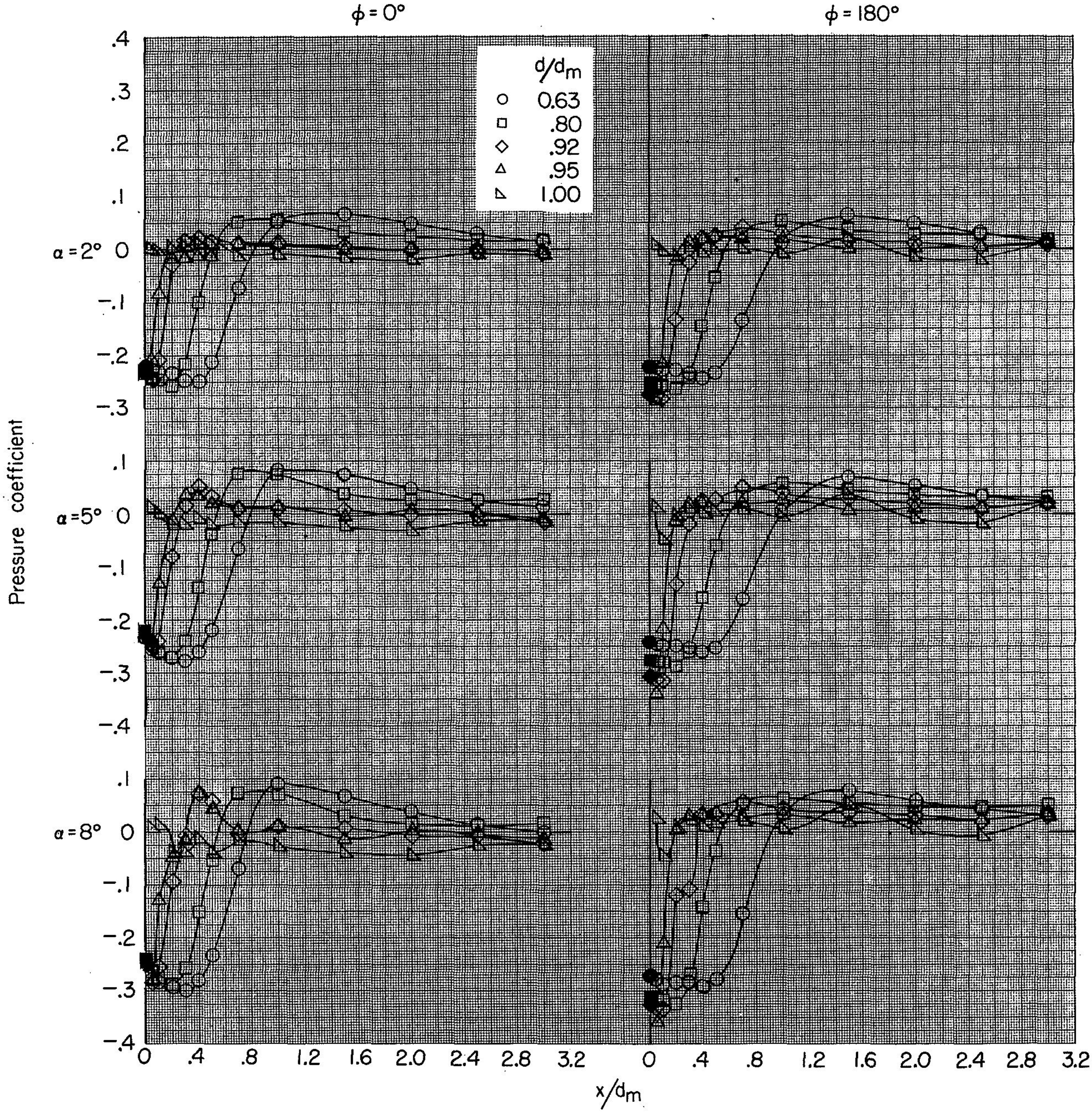
(m) M = 1.20. Concluded.

Figure 4.- Continued.



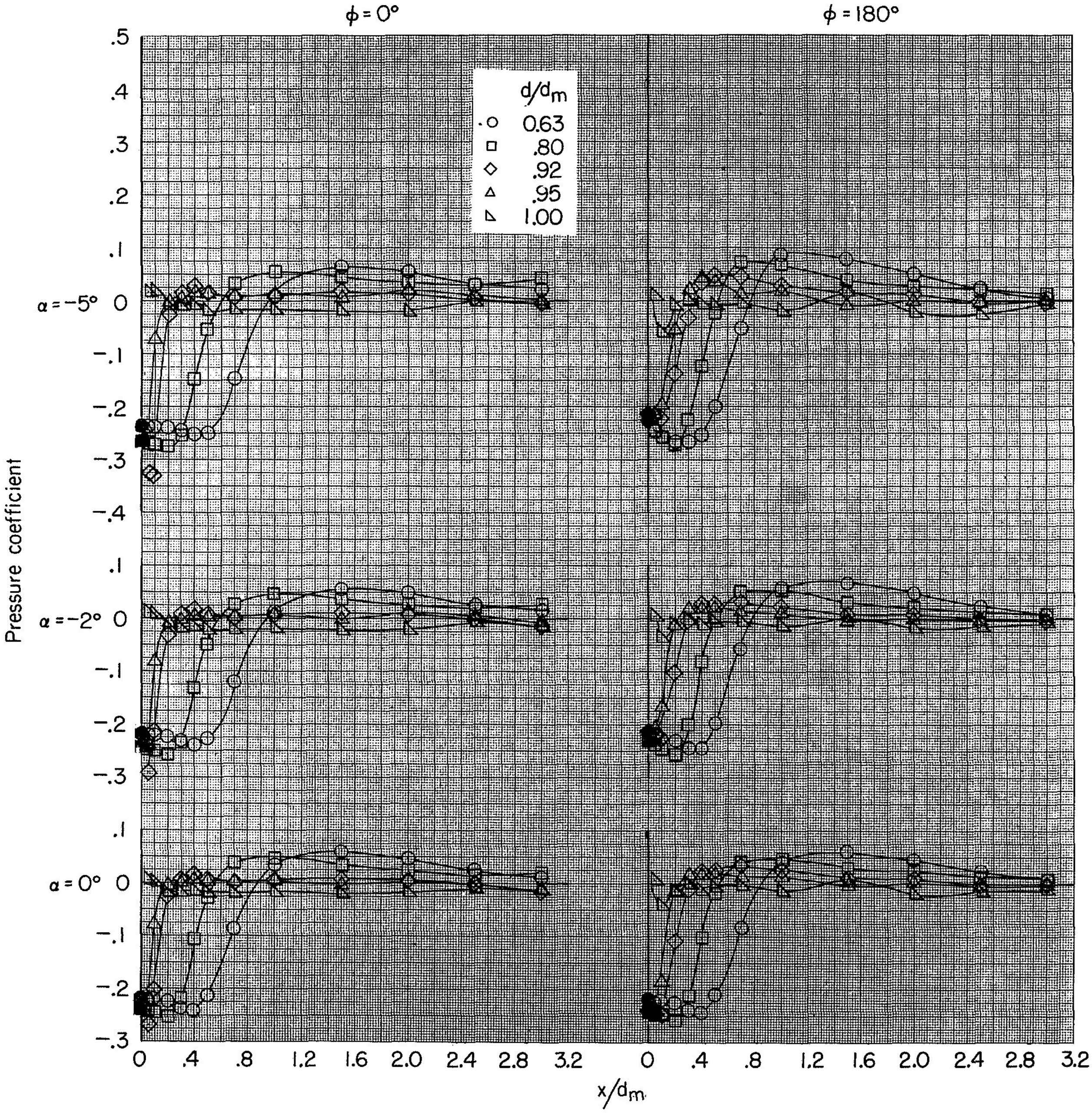
(n) M = 1.25.

Figure 4.- Continued.



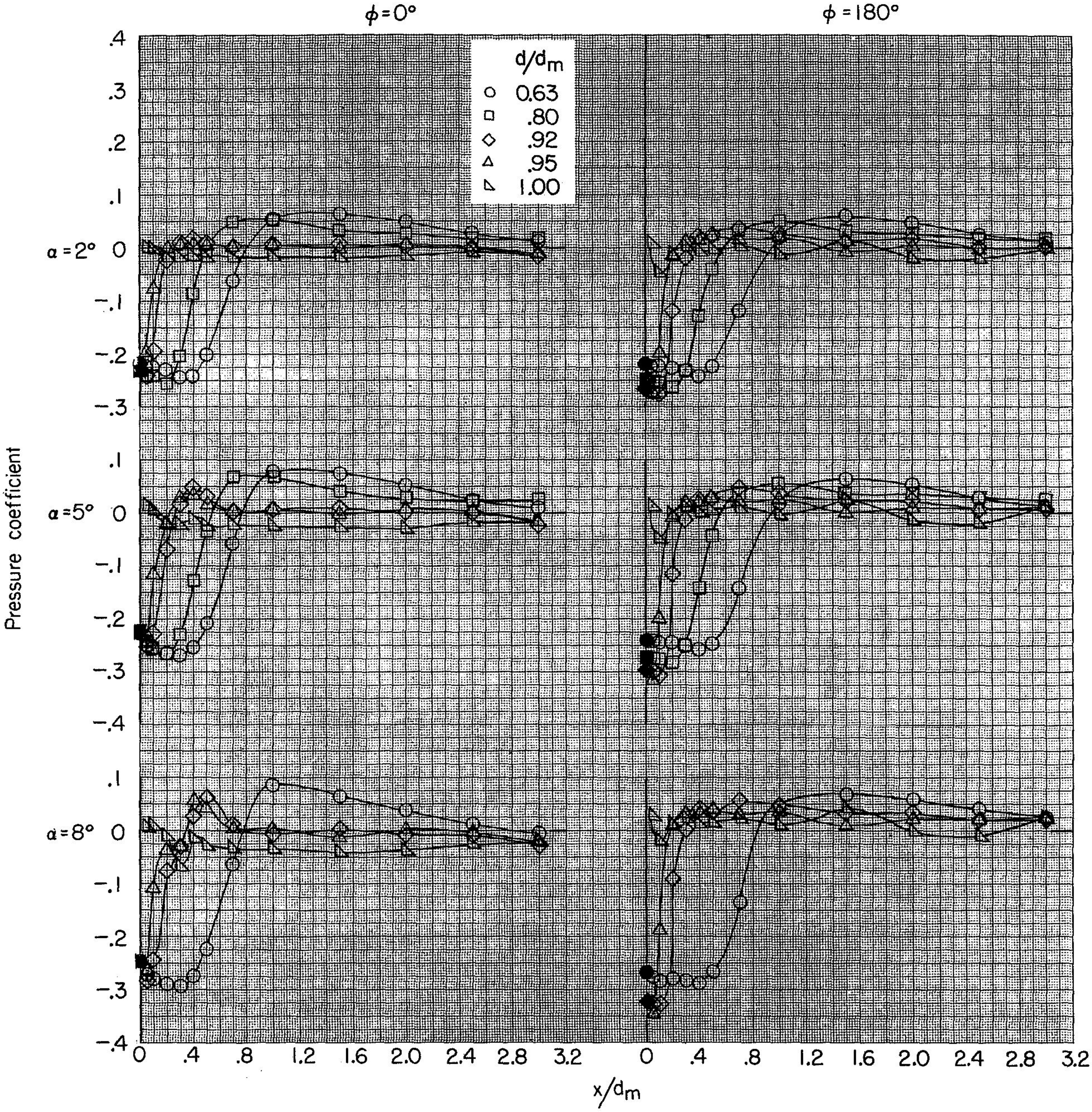
(n) M = 1.25. Concluded.

Figure 4.- Continued.



(o) M = 1.30.

Figure 4.- Continued.



(o) M = 1.30. Concluded.

Figure 4.- Concluded.

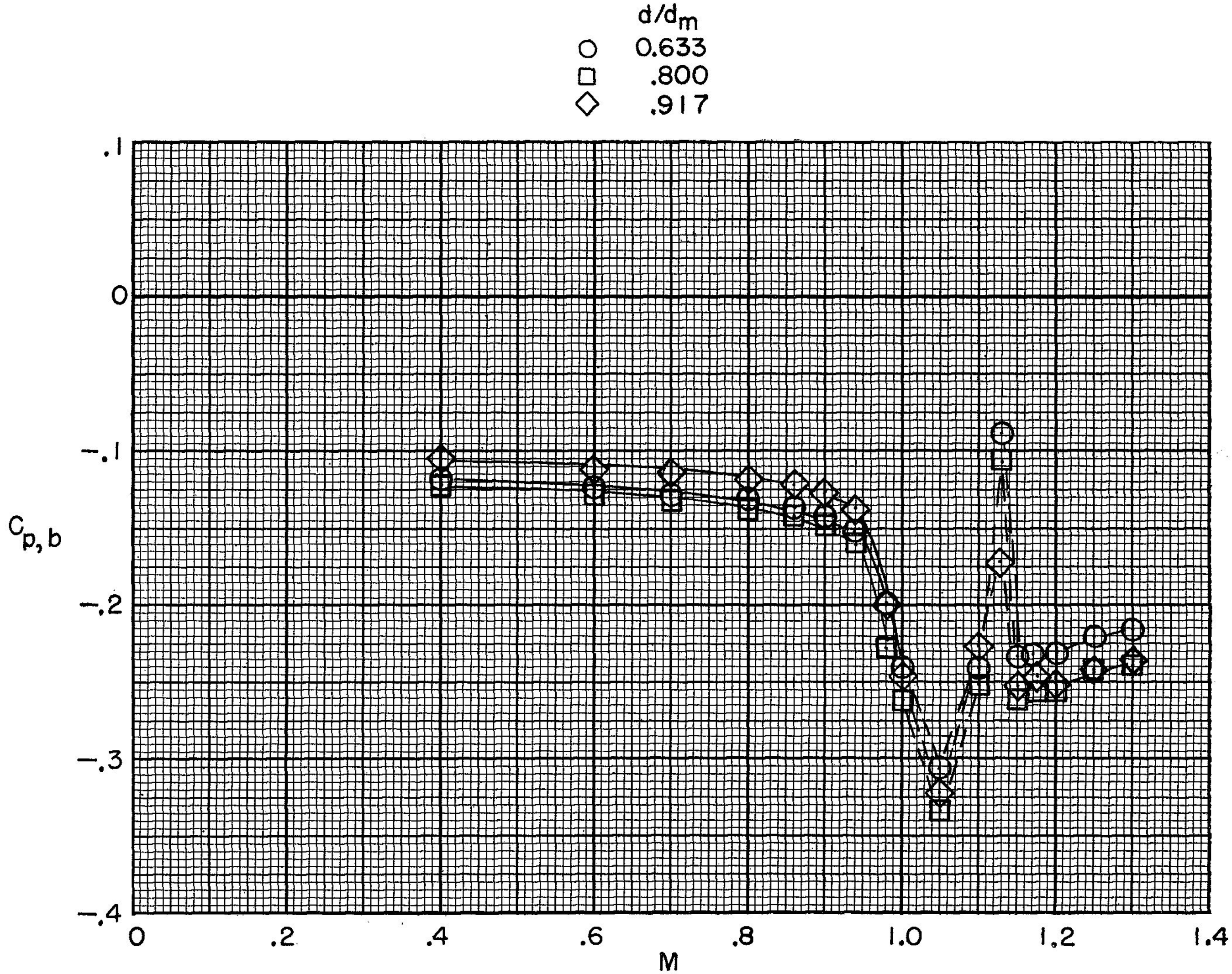


Figure 5.- Effect of step height on variation of step base pressure coefficient with Mach number at $\alpha = 0^{\circ}$.

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